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*Full Length Research Paper*

# **Extended distribution of testate amoebae (Protozoa: Rhizopoda) to Indian fauna from Sangla Valley, Himachal Pradesh, India**

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Received 14 March, 2019; Accepted 20 May, 2019

**Testate amoebae are a group of free-living heterotrophic protists that have an organic shell or test and play a very good role as bioindicators in the ecological monitoring of environment. In spite of the importance the percentage contribution of free living protozoans recorded from the Himalayan landscape is only about 12% of the total free living protozoans of India. This portrays a meagre diversity of species from such a highly diversified ecosystem of Himalaya and the true diversity may be far above the recorded number of species. In this study it is herewith reporting two species of testate amoebae viz., *Assulina quadratum* Van Oye, 1958 and *Cyclopyxis leidy* Couteaux et Chardez, 1981 for the first time from India from Sangla Valley, Himachal Pradesh.**

**Key words:** *Assulina quadratum*, *Cyclopyxis leidy*, bioindicator protists, moss-dwelling testate amoebae, soil protists, new biogeographic records, Sangla Valley, Himachal Pradesh, India.

## **INTRODUCTION**

Testate amoebae are a group of shelled protozoa that occur in high density populations in all environments and form a very environmental sensitive group of organisms (Nguyen-Viet et al., 2007). Their short generation times make them useful indicators of environmental changes (Vincke et al., 2004a; Mattheeussen et al., 2005). Nguyen et al. (2004) suggested that testate amoeba might be considered as potential biomonitors for atmospheric pollution. Testate amoebae are sensitive to physical changes of the surrounding environment; e.g., the moisture content (Beyens et al., 1986; Sullivan and Booth, 2011), temperature (Tsyganov et al., 2013) and they can be used as a model organism for environmental studies and ecotoxicology (Payne et al., 2012). In spite of

the importance of this group of microorganisms for ecological monitoring not much research has been done in India. Even though Chattopadhyay and Das (2003) reported an appreciable number of moss dwelling testate amoebae from North and North-East India, no species have been reported from Sangla Valley, the present study area in the state of Himachal Pradesh, which is a Western segment of the Indian Himalayan region. The Himalayan region is a rich repository of extremely varied native and endemic biodiversity and is recognized as one of the globally important biodiversity hotspots (Rana et al., 2012; Sharma and Samant, 2014). This study is as part of the comprehensive study of the faunal diversity of Sangla Valley by Zoological Survey of India, India. It is

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Figure 1. *Assulina quadratum* Van Oye, 1958.

herewith a report of 2 species of testate amoebae for the first time from India from moss habitats of Sangla Valley viz., *Assulina quadratum* Van Oye, 1958 and *Cyclopyxis leidy* Couteaux et Chardez, 1981.

#### MATERIALS AND METHODS

The moss samples for the study were obtained from high altitude regional centre of zoological Survey of India, Solan. Moss samples were collected (100-200 g) by quadrant sampling (1 m<sup>2</sup>) by scraping with a spatula from rock from Sangla Valley. Sangla Valley is located at latitudes 31° 10' 1.00"-31° 30' 17.16" N and longitudes 78° 10' 26.52"-78° 52' 41.75"E and with altitudes varying from 1800 to 4600 m. The samples were processed using a non-flooded petri dish method as described by Foissner (1992) and kept 24 h for culture. The samples were then placed dropwise on glass slides with a micropipette and investigated under a compound microscope Nikon 50i for identification up to species level. The magnification used was 400X.

#### RESULTS

The study revealed the addition of two species of testate amoebae to Indian testate fauna from Sangla Valley. All the slides were registered and deposited in the National Zoological collections of Marine Biology Regional Centre of Zoological Survey of India, Chennai, Tamil Nadu, India.

(i) Systematic position of *Assulina* Ehrenberg (1872)  
Phylum Cercozoa Cavalier-smith (1998)  
Class Silicofilosea Adl et al. (2005)

Order Euglyphida Copeland (1956)  
Family Assulinidae Lara et al. (2007)  
Genus *Assulina* Ehrenberg (1872)

This genus is characterized with brown colour and ovoid test formed of compressed, elliptical, imbricated, siliceous platelets arranged more or less regularly in diagonal rows; aperture oval, terminal truncate or with a short neck bordered by a thin chitinous dentate membrane.

*Assulina quadratum* Van Oye, 1958 (Figure 1).

Material examined includes: Slide Nos. Mi-680; Mi-655; 4 specimens; Date of collection, 10.10. 2017, Collected by Sidhu and party.

#### Description

*Assulina quadratum* van Oye, 1958 has a triangulate, oval-shaped, light-brown coloured test covered with small oval-shaped platelets arranged in a linear manner. The posterior end of the test is slightly bifurcated; the opening of the aperture is serrated with several fine lobes. The shell length ranges from 41 to 45 μm, breadth of the shell is 34 to 36 μm and length of oral aperture is 10 to 12 μm. The occurrence of *Assulina* is frequently seen among moss habitats.

(ii) Systematic position of *Cyclopyxis* Deflandre (1929)  
Phylum Amoebozoa Luhe, 1913, emend. Cavalier-Smith (1998)  
Class Tubulinea Smirnov et al. (2005)  
Order Arcellinida Kent (1880)



Figure 2. *Cyclopyxis leidy* Couteaux and Chardez, 1981.

Family Trigonopyxidae Loeblich and Tappan (1964)  
Genus *Cyclopyxis* Deflandre (1929)

Test brown, regularly arched, in lateral view hemispherical, encrusted with mineral particles; aperture central, invaginated and circular; some species with lobed pseudostome, margin is never thick with organic lip, large sand grains encrusted in the test.

*Cyclopyxis leidy* Couteaux et Chardez, 1981 (Figure 2). Material examined includes Slide Nos. Mi. 681; Mi. 683; 3 specimens; Date of collection 9.10.2017, collected by Sidhu and party.

### Description

Test hemispherical, ventral surface smooth; pseudostome is in the centre, bordered with three broadly rounded lobes which are bending downwards bordered by a smooth chitinous rim. The shell length ranges from 70 to 80  $\mu\text{m}$  and height 35 to 40  $\mu\text{m}$ ; aperture width 18-20  $\mu\text{m}$ . The habitat of *Cyclopyxis* is mostly dry mosses.

### DISCUSSION

Perusal of literature revealed that only two representative species of *Assulina* viz., *Assulina muscorum* Greeff, 1888 and *Assulina seminulum* (Ehrenberg, 1848) were reported from different states of North and North East India (Chattopadhyay and Das, 2003), Andhra Pradesh (Das et al., 2004) and Himachal Pradesh (Bindu, 2018). Thus, the present report of *Assulina quadratum* extends

its distributional range to India and all the species reported under the genus *Assulina* from various states are from moss habitats and considered to be the typical inhabitants of mosses. The species under the genus *Cyclopyxis* reported from India are *C. arcelloides* Deflandre, 1929, *C. euryostoma* Deflandre, 1929 and *C. kahli* Deflandre, 1929 (Chattopadhyay and Das, 2003; Das et al., 2004; Bindu, 2018) and in this communication reporting an additional species of *Cyclopyxis* viz., *Cyclopyxis leidy* Couteaux and Chardez, 1981 to Indian testate fauna. The testate amoebae fauna of India is not thoroughly studied and further intensive study of this group may add many more species to the list of Indian fauna.

### CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

### ACKNOWLEDGEMENTS

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*Full Length Research Paper*

# Threats and their relative severity and driving forces in the African Elephant range wildlife protected areas of Ethiopia

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**Anthropogenic threats to five wildlife protected areas (PAs) in Ethiopia: Omo, Mago, Chebera Churchura and Kafta Sheraro National Parks, and Babilie Elephant Sanctuary were studied. The study specific objectives were to: (i) establish the relative severity of threat factors to the PAs and susceptibility of the PAs; (ii) explore underlying causes of the threats; and, (iii) identify appropriate threat mitigation measures. A semi-structured questionnaire survey was administered to 25 most experienced staffs of the PAs. Indexes of threat factor severity and vulnerability of PAs to these threats were calculated and the 'Theory of Change Model' to identify threat mitigation measures was used. Twelve major threat factors operating in the five PAs were identified. Five (~39%) of the threat factors were operating at higher level than the average RTFSI score, with wildlife poaching, subsistence farming and overgrazing being the three top severe threats. Babilie Elephant Sanctuary, and Kafta Sheraro and Omo National Parks appeared to be susceptible to the majority of threat factors identified. The underlying causes of the threat factors were almost similar across the PAs and included several factors such as political, socio-economic and ecological. The impacts of these threat factors on biodiversity and mitigation strategies are discussed in detail.**

**Key words:** Anthropogenic threats, management effectiveness, poaching, protected area susceptibility, theory of change model, threat severity.

## INTRODUCTION

Most international agreements concerning biodiversity conservation (e.g., the Convention on Biological Diversity, United Nations Framework for Combating Climate Change, The Ramsar Convention, etc.) view protected areas (PAs) as the principal tool available for

*insitu* conservation and sustainable use of biodiversity and critically important ecosystems (UNEP-WCMC et al., 2018). As such, these agreements call for party countries to establish and maintain networks of protected areas (PAs) to effectively safeguard and reduce human

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pressures to biodiversity. These initiatives have resulted to substantial increase both in number and coverage of PAs in many countries, as well globally (UNEP-WCMC et al., 2018). Despite this, however, it remains controversial how effective these PAs are in protecting biodiversity. Some studies highlight that PAs are indeed able to reduce threats to biodiversity such as deforestation and poaching (Andam et al., 2008; Asefa et al., 2015; Eklund et al., 2016; Biplab et al., 2017), yet effectiveness varies considerably depending on socio-economic, political and ecological contexts of the countries or the regions considered (Geldmann et al., 2013; Barnes et al., 2016; Coetzee, 2017). Some other studies report that many PAs are still experiencing species declines (Geldmann et al., 2013). This is particularly true in developing countries where limited conservation funding, immediate needs of local communities, development pressures and increasing demands on natural resources, overlap to create considerable challenges in the effective management of PAs (Andam et al., 2008; Eklund et al., 2016; Coetzee, 2017).

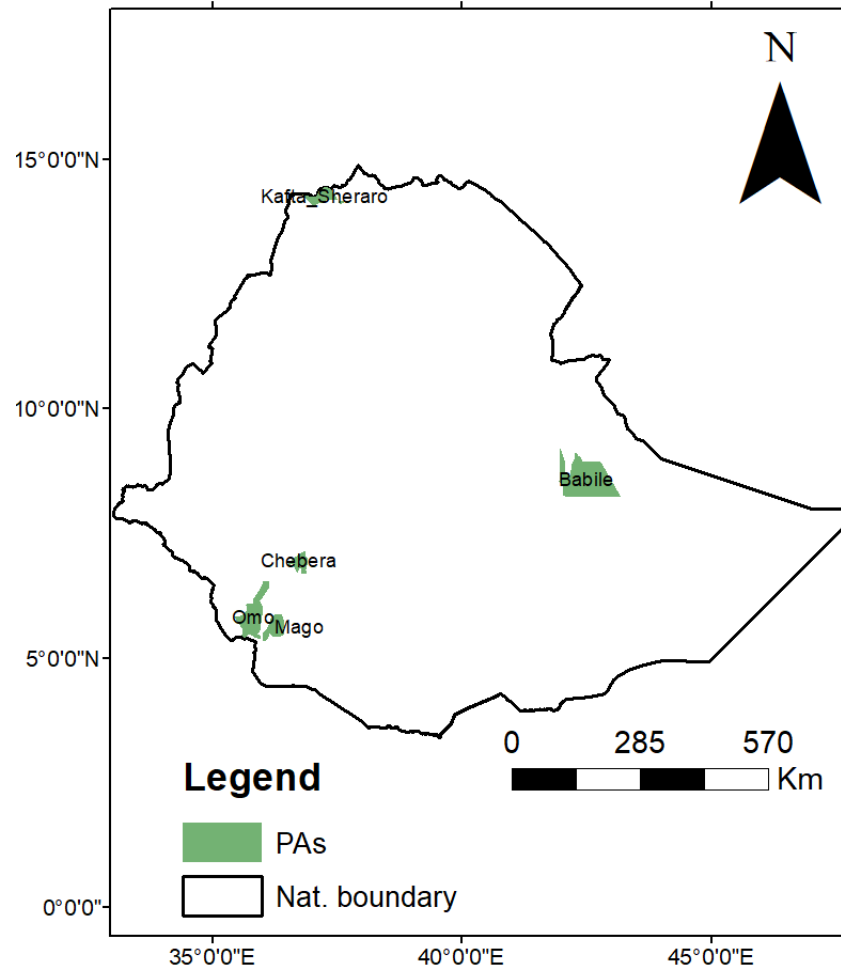
Ethiopia is characterized by possessing high diversity and endemism of biodiversity in the African continent. Initiatives to conserve this unique biodiversity of the country were formally started in late 1950s through the establishment of wildlife conservation areas such as National Parks (Vreugdenhil et al., 2012). Given the large dependence of Ethiopian nations' livelihood, directly or indirectly, on natural resources; designation of PAs in the country have been seen as a cornerstone strategy to preserve the diverse and unique wildlife and their associated ecosystems, as well as to maximize their contribution to sustainable development of the country (Zyl, 2015). To-date, there are about 73 wildlife PAs in the country falling under six management categories: 27 national parks, 2 wildlife sanctuaries, 6 wildlife reserves, 25 controlled hunting areas, 5 biosphere reserves and 8 community conservation areas. In total, they cover 93,182 km<sup>2</sup>, accounting for about 8% of the total land mass of the country (Vreugdenhil et al., 2012). Most of these PAs were designated in the last two decades, likely reflecting improved recognition of the current government of the importance of biodiversity to Ethiopian people's wellbeing. Despite the increasing trend in number and coverage of PAs in the country and improved government's commitment to biodiversity conservation, most of Ethiopia's PAs have been ineffective at reaching their objective of protecting and maintaining biodiversity, ecological processes and ecosystem services (Jacobs and Schloeder, 2001; IBC, 2005; EWCA, 2015; Zyl, 2015). The major problems to Ethiopia's wildlife conservation in the past had been partly attributed to the adoption and implementation of 'exclusionary' wildlife policies, which had led local communities to develop a negative attitude that PAs and wildlife belong to the state/government and exploit natural resources in an unregulated manner (Jacobs and Schloeder, 2001).

Although this past wildlife policy has been revised by the current government in such a way that accommodates the needs and aspirations of local communities, effectiveness of this 'inclusionary' policy in promoting sustainable preservation and utilization of wildlife resources of the country has been questionable due to its poor implementation (IBC; 2005; EWCA, 2015).

While policy factors are among the underlying causes for ineffectiveness of PA management, threats to biodiversity in Ethiopia are primarily attributed to the rapidly growing human population and the consequently increasing demand of natural resources for subsistence (IBC, 2005; Vreugdenhil et al., 2012). Thus, anthropogenic activities have adversely affected wildlife of the country directly through poaching/killing and indirectly by causing habitat loss and fragmentation. Such activities have resulted in a decline both in number and distributional ranges of populations of many of the most charismatic species in the country, such as Elephants (*Loxodonta africana*), Ethiopian Wolf (*Canis simensis*), Mountain Nyala (*Tragelaphus buxtoni*) and Walia Ibex (*Capra walie*) (Asefa, 2008; EWCA, 2015; Wale et al., 2017). The cumulative effects of biodiversity degradation brought about by human-induced threats have contributed to a continued decline in ecosystem functioning and processes and ecosystem service delivery of the PAs: For example, drying-out of perennial rivers, land degradation, erosion and flooding, heightening the vulnerabilities of Ethiopian people and the impacts of climate change (IBC, 2005; Wale et al., 2017).

It is therefore apparent that, given the actual and potential valuable role of PAs in fostering biodiversity conservation, understanding whether and why PAs are achieving success is essential to maintain, or improve, the way PAs are managed by investigating the relationship between management actions and biodiversity condition (Timko and Innes, 2009; Pyhälä et al., 2019). However, only limited attempts have been made in Ethiopia to regularly evaluate the status and threats of the PAs (e.g. Asefa et al., 2015; Wale et al., 2017; Gebre, 2018). This lack of information on the nature and severity of threats across PAs of Ethiopia has led managers to apply the same threat mitigation strategies across the existing PAs; however, such application of similar strategies may not have any meaningful gains even in the years to come. Thus, in order to plan to address the threats and mitigate their adverse impacts on biodiversity in Ethiopia's PAs, assessment of the nature and severity of threat factors undermining biodiversity conservation is required; especially within and/or across PAs that are currently thought to be under severe anthropogenic pressures. The findings will provide key insights on the formulation of workable conservation action plans specifically targeting conservation problems of each PA.

To-date, several types of tools have been developed and in use for evaluating PA management effectiveness,



**Figure 1.** Location of the study protected areas in Ethiopia.

such as the widely used Management Effectiveness Tracking Tool (METT) (Hockings et al., 2006). However, such standard tools give much emphasis on the actual management process through rapid assessments using scorecards and lack an assessment of the state of biodiversity or ecosystems (Hockings et al., 2006; Cvitanovic et al., 2014). This limits the analysis of how management interventions relate to PA outcomes (Carranza et al., 2014). On the other hand, most PAs lack resources (expertise, finance and/or time) to collect intensive field-based ecological data needed to relate management interventions to threat level and/or to state of biodiversity (that is, to evaluate the effectiveness of past and present management interventions made in reducing the threats and their impacts) (Asefa et al., 2015; Pyhälä et al., 2019). To overcome such limitations, in this study we used “The Theory of Change Model” tool to assess severity of threat factors in five PAs of Ethiopia and to explore potential management interventions required. This tool is more appealing to researchers/conservationists because information used for rigorous

impact evaluation of PA effectiveness could easily be obtained from researchers' and/or PA managers' perceptions (Cvitanovic et al., 2014; Pyhälä et al., 2019). In addition, this tool also enables one to investigate and create linkages between threat factors, biodiversity affected, underlying causes of the threats, remedial actions needed and how to monitor impacts (outcomes) of management interventions (Laing and Todd, 2015; Pyhälä et al., 2019). Previous similar threat assessment studies (e.g., Cvitanovic et al., 2014; Pyhälä et al., 2019), although not in a strict sense identical to “The Theory of Change” we adopted in this study, have reported the reliability of information obtained from experienced researchers and PA managers/experts for drawing sound conclusions and recommendations.

The present study was conducted at five PAs: Omo, Mago, Chebera Churchura and Kafta Sheraro National Parks and Babille Elephant Sanctuary (Figure 1). These PAs are known to harbor the largest viable populations of the African Elephant remaining in the country, a species severely threatened by human actions. In the meantime,

these PAs have also been assumed to be the most affected wildlife conservation areas in Ethiopia from human activities, but the level/severity of the threat factors and their impacts are yet to be known (EWCA, 2015). The project management team needed threat data for these five PAs to use as input for formulation of Management Plans for the PAs, as well as baseline against which progress and success of the project will be evaluated (EWCA, unpubl. document).

The specific objectives of the study were to: (i) establish the relative severity of threat factors to the five Ethiopia's PAs; (ii) prioritize and rank the PAs based on the relative severity of threat factors operating against them; (iii) identify underlying causes of the threats; and, (iv) identify appropriate threat mitigation for each and/or all the PAs.

## MATERIALS AND METHODS

### Study areas

The present study was initiated by the GEF/UNDP-funded project, "Enhanced Management and Effectiveness of Ethiopia's Protected Areas". It is a six-year project (2018-2023) implemented by the Ethiopian Wildlife Conservation Authority (EWCA) at five selected pilot PAs: Omo, Mago, Chebera Churchura and Kafta Sheraro National Parks and Babilie Elephant Sanctuary (Figure 1). Omo National Park (ONP) was established in 1968 and has a total area of 2,936 km<sup>2</sup>. Adjacent to ONP is the Mago National Park (MNP), which was established in 1970 and has an area of 1,942 km<sup>2</sup>. Both ONP and MNP are found in the southern region of Ethiopia (Vreugdenhil et al., 2012). With an area of 6,900 km<sup>2</sup>, Babilie Elephant Sanctuary (BES) was established in 1970. It is situated in the semi-arid areas of the eastern part of the country and contains an estimated population of 250 elephants (Belayneh et al., 2011). Lying in the north-western tip of the country, Kafta Sheraro National Park (KSNP) has an area of 2,176 km<sup>2</sup>. It was originally established as a wildlife reserve but upgraded to a national park in 2007. The park has an isolated elephant population in the country (estimated at 300 animals); this is the most northern population of elephants on the continent (EWCA, 2018). All the four PAs (ONP, MNP, KSNP and BES) have similar elevation (ranges from 400-1,800 m.a.s.l.), major vegetation types and climatic conditions. Vegetation of the PAs can be generally described as savannah woodlands, riparian forest, open grassland, and bushland. The main rainy season in the areas is from July-September, with a short rainy season from March-April (Demeke, 2008).

Chebera Churchura National Park (CCNP) was established in 2004 and contains an estimated population of 430 elephants. CCNP covers an area of 1,215 km<sup>2</sup> and altitude of the park ranges from 550 to 1700 m.a.s.l. The natural vegetation of the park can be classified into four major types: Montane forests in the eastern and north western highlands, riparian forests along the rivers, woodland vegetation in the southern part, and scrubland that covers the central and largest part of the Park (Belayneh et al., 2011).

### Data collection

The study mainly used primary data obtained through semi-structured questionnaire surveys (Bargali et al., 2007, 2009; Pandey et al., 2011; Parihaar et al., 2015) which were augmented by data collated from literature review. To assess the severity of

threat factors, biodiversity component affected, underlying causes of threats and management actions needed to avert the threats, we designed and administered a questionnaire survey in November 2018 to 25 key PAs' staff (managers/wardens, experts and senior game rangers). These figures represent more than two-thirds of the total number of experienced staff available with each PA. The questionnaire was structured into four parts. Part I targeted threat severity level where respondents from each PA were asked to score each of the threats they mention to be occurring in the respective PA where they were working. Scoring was done for each of the threats they mentioned on a numerical scale ranging from 1 as the lowest threat level to 3 as the highest. To help them determine the scale of score to be assigned to each threat factor, the interviewees were informed to take into account the following four criteria: Level of damage caused, permanence (potential for permanent damage/loss), scope (geographic extent of occurrence), and status (increasing/decreasing) (Kinahan and Laurenson, 2013). Part II targeted the underlying causes of the threats, that is, indirect threats or driving forces and challenges to eliminate the threats and achieve effective PA management. Part III targeted biodiversity components (ecosystem, habitat type and species) most affected by each, or combination, of the threat factors. Finally, part IV targeted management actions needed to address the challenges so as to abate or mitigate the threats. The questionnaires were filled in by five representatives for each PA (total of 25 interviewees across the five PAs) and we received completed questionnaires for all interviews.

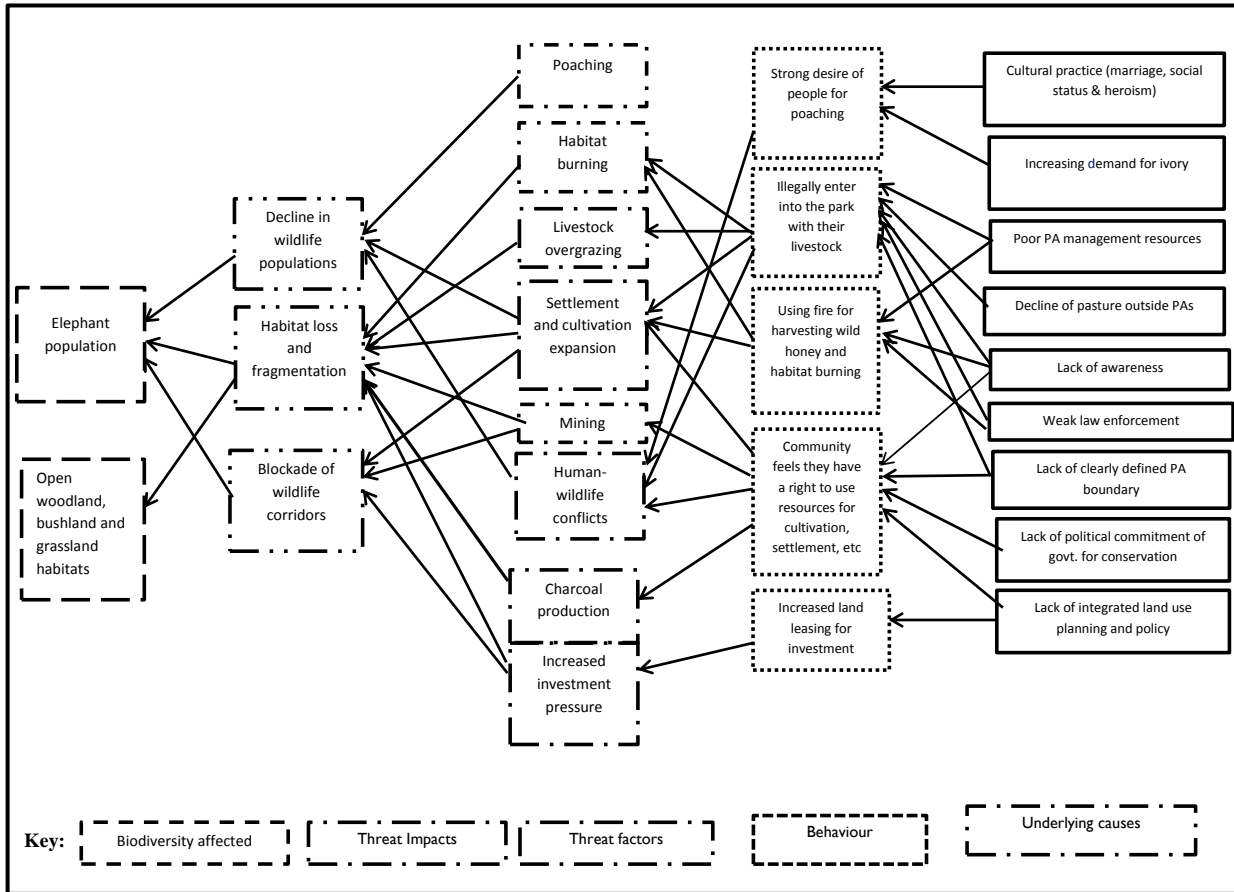
Secondary data were collected through desk reviews of all relevant documents which include past management plans published and unpublished research articles, monthly and annual reports and other relevant government documents.

### Data analysis

For Part I of the questionnaire, we calculated indexes of threat factor severity and vulnerability of PAs to these threats. Accordingly, the following indexes were calculated (Kiringe and Okello, 2007):

1. Protected Area Susceptibility Index (PASI) to the threat factors = (Number of threat factors mentioned for each PA / Total number of threat factors identified by the interviewees across PAs, 12)
2. Mean Score of Each Threat Factor = (sum of all the scores for a particular threat factor / the total number of respondents, 25)
3. Relative Threat Factor Severity Index, RTFSI = (The mean score for a particular threat factor / The maximum possible score, 3)
4. Relative Threat Factor Severity Index [within a PA], RTFSI<sub>(within)</sub> = (The mean score for a particular threat factor within a PA arranged in ascending order)
5. Protected Area Relative Threatened Index, PARTI = (Total score of the twelve threat factors from the interviewed officers of a given protected area) / Total responses = 60)

A ranking system based on: (i) RTFSI shows which of the threat factors is more serious across the PAs considered, (ii) both PASI and PARTI shows which PAs were most vulnerable to the identified threat factors, and (iii) Relative Threat Factor Severity Index (rank) within a PA, RTFSI<sub>(within)</sub>, shows which of the threat factors was more serious within a PA or which PA is most vulnerable to which threat factor. As responses to the remaining parts of the questionnaire were qualitative, numeric analyses were not conducted. Instead, they were compiled in thematically structured notes and tables and used to construct the theory of change model. Any textual notes entered were compiled to assist in explaining the results. Findings where applicable were presented, both in aggregate form across PAs and PA-specific. Then, the theory of



**Figure 2.** A conceptual framework model (based on the result of situation analysis) demonstrating the links between the current state of threat factors, underlying causes (and behaviors) of threats, impact of threats on biodiversity and component of biodiversity impacted.

change model following seven steps was developed (detail of the description of how to construct the theory of change model are given in Conservation International, 2013; Laing and Todd, 2015):

Step 1: Situation analysis, developing a conceptual framework model linking the threat factors, underlying causes (bearers and challenges to mitigate the threat factors), human behavior, the effect of threat factors on biodiversity, and biodiversity component (species, habitat, ecosystem, etc.) most affected.

Step 2: Defining long-term goal(s) of PA management.

Step 3: Mapping the pathway to change, building results framework (defining outputs, outcomes and goal of implementing management interventions).

Step 4: Selecting a set of activities (management interventions) to achieve the results.

Step 5: Identifying indicators to track progress.

Step 6: Selecting progress [indicators] monitoring methods.

Step 7: Articulating key underlying assumptions that demonstrate the potential functionality of the theory of change model.

The conceptual framework model of the situation analysis relates the threat factors, human behaviors, underlying causes of threat factors, impacts of the threat factors on biodiversity, and biodiversity components most affected by the threat factors (Figure 2). The Theory of Change Model, on the other hand, is simply the reverse of the situation analysis model that depicts the expected results

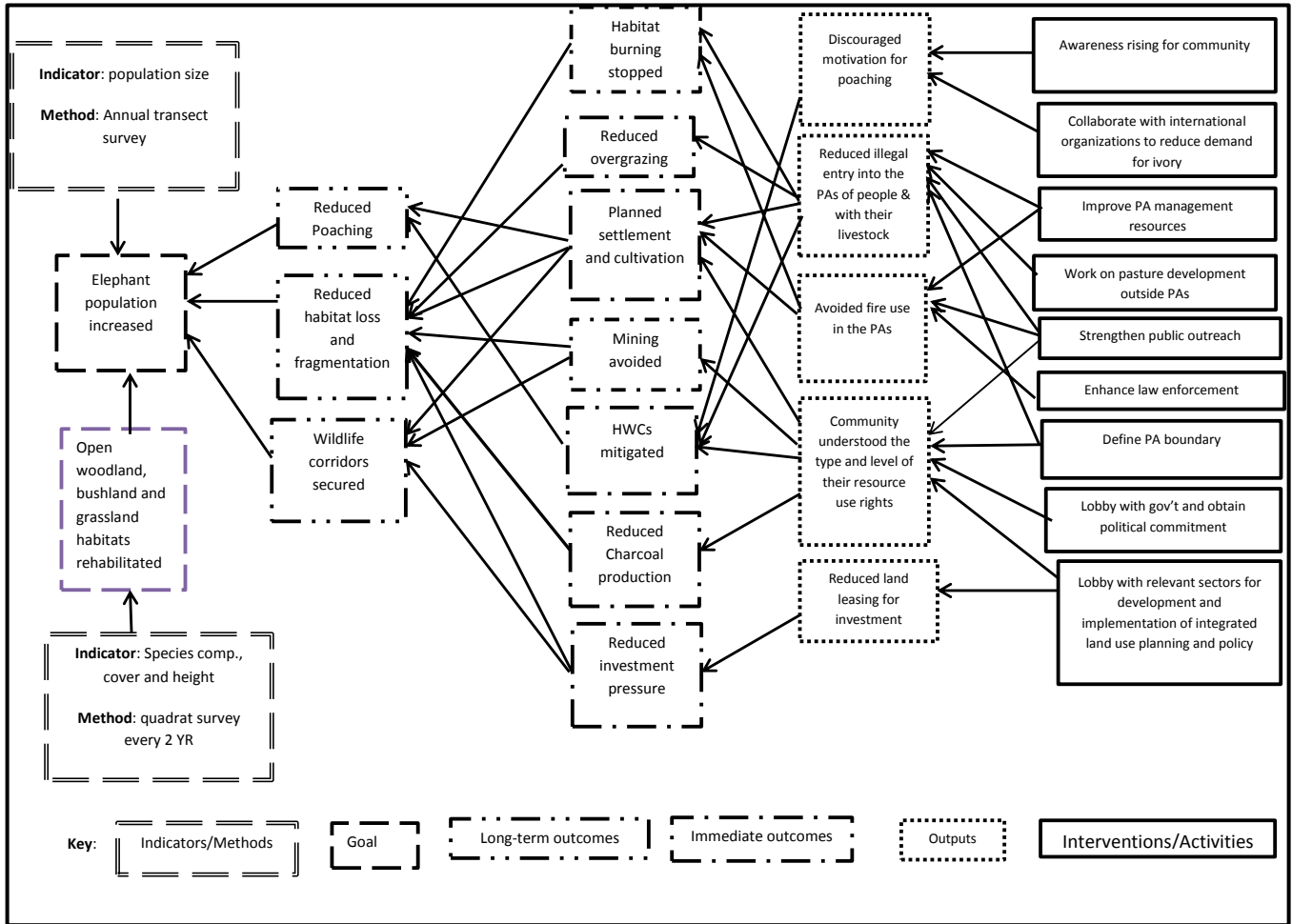
(e.g., behavioral change, reduced incidence of threat factors, reduce level of threat impacts, etc.) achieved if the underlying causes of the threat factors are acted upon. As such, it demonstrates the links between work plan (management interventions/actions needed to reduce threat factors), human behavioral change results (outputs of interventions), outcomes (threat reduction results), goal (intended impact of intervention on the target biodiversity), and progress indicators and methods to measure the indicators (Conservation International, 2013) (Figure 3). Both the situation analysis model and the theory of change model were initially constructed for each PA, but only one of each type that represents all the PAs were presented here. The reason for merging this was because most of the threat factors, the underlying causes, human behaviors and the target ecosystem components most affected by the threats (that is, elephant population and its critical habitats) were, at least, qualitatively, similar across the five PAs.

## RESULTS

### Severity of threat factors across protected areas

Twelve threat factors affecting the five PAs studied were identified, with relative threat factor severity index





**Figure 3.** Theory of change model demonstrating the links between work plan (management interventions/actions needed to reduce threat factors), behavioral change results (outputs of interventions), outcomes (threat reduction results), goal (intended impact of intervention on the target biodiversity), and progress indicators and methods to measure the indicators.

(RTFSI) ranging from 0.01 to 0.67. Five (~39%) of the threat factors were operating at higher relative severity level than the average RTFSI score of all threat factors (mean ± se = 0.35 ± 0.05) (Table 1). These included those threat factors that were widespread, occurring almost in all the PAs, such as wildlife poaching for bushmeat and for their products (ivory, skin, etc.) (RTFSI = 0.67), expansion subsistence agricultural (RTFSI = 0.59) and overgrazing by livestock (RTFSI = 0.53). Other threat factors with higher than, or equal, to the average RTFSI, and occurring in three or four PAs, included the following: Investment pressure/large scale irrigation (RTFSI = 0.45), small scale expansion of permanent agriculture (RTFSI = 0.40), and human-induced fire burning RTFSI (0.35). The rest of the threat factors were localized (occurring only in one or two PAs) and had RTFSI values lower than the average RTFSI (Table 1).

Three of the five PAs appeared to be susceptible to the majority (over half of the total) of threat factors identified. These PAs were: BES which was susceptible to 10 threat

factors (Protected Area Susceptibility Index (PASI) = 0.83), KSNP which was susceptible to 9 threat factor types (PASI = 0.75), and ONP susceptible to 8 threat factor types (PASI = 0.67) (Table 2). The PA relative threatened index (PARTI) values provided in Table 2 showed that two PAs (KSNP: PARTI = 1.42; and BES: PARTI = 1.18) had PARTI values of greater than the average index value (average PARTI = 1.05) of the five PAs.

### Severity of threat factors within protected area

Interestingly, this analysis of relative threat factor severity [RTFSI<sub>(within)</sub>] in each PA enabled us to disclose those threat factors that are localized, and thus which would have been considered as of little conservation concern. These localized threat factors are found to be detrimental to biodiversity conservation at a local scale (that is, within the PA where they occurred). For example, both canal

**Table 1.** Sum and mean threat factors score (n = 25) and Relative Threat Factor Severity Index, RTFSI<sub>(across)</sub> of the 12 threat factor types identified across the five protected areas.

| Threat factor                              | Sum of threat factor score | Mean ( $\pm$ SE) threat factor score | Relative threat factor severity index (RTFSI) |
|--|----------------------------|--------------------------------------|---|
| Poaching                                   | 51                         | 2.00 $\pm$ 0.32                      | 0.67  |
| Overgrazing                                | 40                         | 1.58 $\pm$ 0.41                      | 0.53  |
| Settlement                                 | 22                         | 0.90 $\pm$ 0.46                      | 0.30  |
| Cultivation/ subsistence farming           | 44                         | 1.76 $\pm$ 0.37                      | 0.59  |
| Human-induced wildfire                     | 26                         | 1.04 $\pm$ 0.44                      | 0.35  |
| Canal Construction                         | 15                         | 0.60 $\pm$ 0.60                      | 0.20  |
| Human-Wildlife Conflict                    | 17                         | 0.66 $\pm$ 0.59                      | 0.22  |
| Deforestation                              | 25                         | 1.00 $\pm$ 0.45                      | 0.33  |
| Mining                                     | 11                         | 0.44 $\pm$ 0.39                      | 0.15  |
| Ethnic Conflict                            | 1                          | 0.04 $\pm$ 0.04                      | 0.01  |
| Investment pressure/large scale Irrigation | 33                         | 1.34 $\pm$ 0.69                      | 0.45  |
| Permanent agriculture (small scale)        | 30                         | 1.20 $\pm$ 0.49                      | 0.40  |
| Mean ( $\pm$ SE)                           |                            | 1.05 $\pm$ 0.57                      | 0.35 $\pm$ 0.05                               |

**Table 2.** Sum of threat factor score within each protected area, protected area susceptibility index (PASI) and relative protected area threatened index (RPATI).

| Name of PA           | Poaching | Overgrazing | Settlement | Subsistence cultivation | Wildfire | Canal | Human wildlife conflict | Deforestation | Mining | Ethnic conflict | Investment | Permanent cultivation | No. threat factors | PASI | Sum scores | PARTI |
|----------------------|----------|-------------|------------|-------------------------|----------|-------|-------------------------|---------------|--------|-----------------|------------|-----------------------|--------------------|------|------------|-------|
| Mago NP              | 15       | 10          | 5          | 5                       | 9        | 0     | 0                       | 0             | 0      | 0               | 0          | 0                     | 5                  | 0.42 | 44         | 0.73  |
| Omo NP               | 10       | 9           | 0          | 4                       | 7        | 15    | 0                       | 0             | 0      | 0               | 15         | 0                     | 6                  | 0.50 | 60         | 1.00  |
| Chebera Churchura NP | 10       | 0           | 0          | 10                      | 0        | 0     | 15                      | 10            | 0      | 0               | 0          | 10                    | 5                  | 0.42 | 55         | 0.92  |
| Kafta Sheraro NP     | 5        | 12          | 5          | 13                      | 10       | 0     | 0                       | 5             | 10     | 0               | 15         | 10                    | 9                  | 0.75 | 85         | 1.42  |
| Babille ES           | 11       | 9           | 12         | 12                      | 0        | 0     | 2                       | 10            | 1      | 1               | 3          | 10                    | 10                 | 0.83 | 71         | 1.18  |

construction for sugar plantation and investment pressure had RTFSI<sub>within</sub> = 3.0, and were the first ranked threat factors in the ONP, while human

settlement expansion had RTFSI<sub>within</sub> value of 2.5 and was ranked first in the BES. Similarly, gold mining in the KSNP was ranked fourth (Table 3).

Otherwise, most of the widespread threat factors discussed above, such as poaching, overgrazing and subsistence cultivation, were also found to be

**Table 3.** Relative threat factor severity index within each protected area [RTFSI<sub>(within)</sub>].

| Threat   | Mago NP | Omo NP  | Chebera Churchura NP | Kafta Sheraro NP | Babille elephant sanctuary |
|--|---------|---------|----------------------|------------------|----------------------------|
| Poaching   | 3.0 (1) | 2.0 (2) | 2.0 (2)              | 1.0 (5)          | 2.1 (3)                    |
| Overgrazing                                      | 2.0 (2) | 1.8 (3) |                      | 2.3 (3)          | 1.8 (5)                    |
| Settlement                                       | 1.0 (4) |         |                      | 1.0 (5)          | 2.5 (1)                    |
| Cultivation/subsistence farming                  | 1.0 (4) | 0.8 (5) | 2.0 (2)              | 2.7 (2)          | 2.3 (2)                    |
| Human induced wildfire                           | 1.8 (3) | 1.4 (4) |                      | 2.0 (4)          |                            |
| Canal construction                               |         | 3.0 (1) |                      |                  |                            |
| Human wildlife conflict                          |         |         | 3.0 (1)              |                  | 0.3 (7)                    |
| Deforestation                                    |         |         | 2.0 (2)              | 1.0 (5)          | 2.0 (4)                    |
| Mining/mineral extraction                        |         |         |                      | 2.0 (4)          | 0.2 (8)                    |
| Ethnic conflict                                  |         |         |                      |                  | 0.2 (8)                    |
| Investment pressure/large scale Irrigation       |         | 3.0 (1) |                      | 3.0 (1)          | 0.7 (6)                    |
| Expansion of permanent agriculture (small scale) |         |         | 2.0 (2)              | 2.0 (4)          | 2.0 (4)                    |

more severe within each PA and appeared to be one of the top-ranked three threats (Table 3).

### Underlying causes of the threat factors and their impacts

The underlying causes of the direct threat factors were, more or less, similar across the PAs. These driving factors were broadly classified into three categories: (i) political factors (policy issues) such as lack of land use planning and low political commitment; (ii) socio-economic factors like increasing human and livestock populations, conservation unfriendly cultural practices, ethnic conflicts, etc.; and (iii) ecological factors, including declining availability and quality of pasture and land degradation, loss of fertility outside PAs and recurrent drought.

The results demonstrated that most of the threat factors identified were posing, probably hardly reversible, adverse impacts on ecosystems, communities and species in the PAs. African Elephant, and its critical habitats, was a species that appeared to be the most affected by the threat factors across all the PAs (Figure 2).

### Theory of change model

Summary result of situation analysis for the PAs (Figure 2), shows that the target ecosystem components (those most affected by the threat factors) were elephant population and its critical habitats. The Theory of Change Model (Figure 3) shows the expected results achieved if the underlying causes of the threat factors are acted upon and thus threats are eliminated or reduced. According to this model, the goal of EWCA and the PA managers in the five PAs is: Improving population status

of African elephant and the quality and quantity of the species' habitat in the PAs.

The potential functionality of the theory of change model's components was demonstrated by five underlying model assumptions, which are briefly described as follow:

1. Awareness raising and community dialogue campaigns [Intervention] would help reduce/avoid wildlife hunting for cultural practices [behavioral change; output] and the demand of bushmeat and ivory [output]. This in turn will result in reduced poaching [outcome] and ultimately to "Increased populations of key wildlife species such as Elephant, etc." [goal].
2. Forging and maintaining strong collaboration with relevant neighboring and middle-east countries [intervention] will result in a reduced demand for ivory [output], thereby reducing poaching [outcome] and improve wildlife populations [goal].
3. Strengthening law enforcement through stakeholder collaboration and adequate resource allocation (finance, equipment and human resources) [intervention] will lead to reduced illegal activities such as unregulated grazing, fire, deforestation for cultivation, etc. [output]", which in turn results to improved wildlife habitat quality [outcome], and ultimately to increased elephant population [goal].
4. Developing and implementation of integrated community development initiatives for communities around PAs [intervention] will reduce people's dependence on PAs' resources [output]. As a result, pressures from cultivation, grazing, illegal settlements etc. will be mitigated [outcome] and wildlife populations and their habitat conditions improved/maintained [outcome].
5. Promoting awareness of local communities and administrators on the importance of the park and wildlife laws and lobbying relevant government officials/bureaus at all levels [intervention] will ensure gaining their political commitment to support wildlife conservation and

incorporate conservation in community priority development agendas [output]. Gaining their commitment will: (i) facilitate defining of protected areas' boundary and gazettement; and (ii) help to mitigate/ reverse the effects of development projects (e.g., sugar factory, irrigation canals and investments in and around some protected areas) on ecosystems [outcome]. Provided that these actions would be taken, then their outcomes and impacts will be "rehabilitation of open woodland, bushland and grassland habitats, especially in Omo and Kafta NPs" and "maintenance of elephant movement corridors" in these parks [outcome]. This ultimately will result in increased population of elephant [goal].

## DISCUSSION

### Severity of threat factors and vulnerability of PAs

The findings of this study highlighted that most of the 12 threat factors identified are occurring in most of the PAs, with wildlife poaching for bushmeat and for wildlife products (e.g., ivory, skin, etc.), expansion of crop cultivation land (subsistence farming) and overgrazing by livestock being the top most severe and most widespread threat factors. These results agree with several similar reports in Ethiopia (e.g., Asefa et al., 2015; Wale et al., 2017; EWCA, 2018) and elsewhere in Africa (e.g., Kiringe and Okello, 2007). The implication of the findings is therefore; although most PAs are susceptible to all of the threats, dealing with poaching and human encroachment and associated activities (e.g., deforestation for cultivation and livestock grazing) in the studied PAs would secure critical habitats/ecosystems and elephant populations in the areas. Whereas, some other threat factors (e.g., large- and small-scale investment irrigation, expansion of permanent agriculture and fire burning) occur at a moderate level (in three or four PAs), the rest of threat factors are localized (occurring only in one or two PAs) and are relatively at lower severity level than the average RTFSI (Table 1).

The findings that a majority of the PAs considered for the study are threatened by a majority of threat types imply that wildlife conservation in the country, in general, and in these PAs in particular, is currently at huge risk. The fact that conservation crisis in Ethiopia has become an overwhelming problem has already been highlighted in reports of several studies and national development plans, including the National Growth and Transformation Plan and Climate-Resilient Green Economy Strategy (EWCA, unpubl. document). In addition to these direct threats, however, a number of bottlenecks to achievement of effective PA conservation and management in the country were identified. These bottlenecks (that is, barriers and challenges to effective biodiversity conservation and PA management), and thus affecting conservation practices independently or interactively,

are related to socio-economic, political and ecological/environmental factors. For example, from socio-cultural/-economic and environmental points of view, the mode of socio-economic activities (e.g., way of cultivation and animal husbandry) in Ethiopia is still the traditional system. Subsequently, areas outside of PAs are currently highly degraded due to unplanned overuse, being confounded by recurrent drought. As such, this ecosystem degradation outside PAs, coupled to the exponential growth rate of human population in the country and where the majority is under high poverty level, has resulted in increasing demand of previously unoccupied virgin land for cultivation and livestock pasture (Vreugdenhil et al., 2012; EWCA, 2015). Ultimately, these challenges have resulted in increased dependency of local communities on the natural resources of the PAs (Acha and Temesgen, 2015; Megaze, 2017); because, relatively intact and productive areas are only available in areas that have been set aside for wildlife conservation. Similarly, conservation incompatible cultural practices, such as killing wildlife to demonstrate bravery and serving bushmeat during marriage ceremonies, and coupled with the increasing demand and price of ivory on the global markets have motivated locals to do poaching.

Another key challenge to contain the wide spreading threats to PAs in Ethiopia is partly attributed to the low capacities of PAs' management to address conservation issues in a holistic approach. Most of the PAs, including those covered by this study, lack until recently clearly defined boundaries and are suffering from shortage of resources (skilled manpower, funding/budget, infrastructure and equipment) needed for effective conservation. Furthermore, PA management systems seldom take into account the need of local communities and the role that they play in pushing conservation forward. This lack of participation of local communities in conservation and management of, and benefit sharing from, PAs; and most importantly, coupled to lack of awareness on the conservation values of wildlife and the associated ecosystems to the society, have led to the local communities to develop the feeling that they are marginalized from conservation initiatives and that wildlife resources are belongings of the government/state. The consequences of such negative attitudes have been increased abuse of natural resources in the PAs, which have been more demonstrated during civil unrest where PA properties and wildlife have been severely destroyed by locals (Jacobs and Schloeder, 2001).

Finally, but the most critically important challenge, lack of political commitment by government bodies, almost at all levels, and lack of appropriate integrated land use plan policies and/or poor implementation are among the key political factors for the intensive and extensive biodiversity degradation in Ethiopia's PAs. One compelling example of the effect of lack of integrated land use plan policy is the recent allocation of land from ONP for large scale

irrigation schemes and cultivation of sugar cane that fed the Omo Kuraz Sugar Factory (Gebre, 2018). Similar incidences have been reported from KSNP where local investors are given irrigation-based cultivation land within the park boundary (EWCA, 2018).

In addition to characterizing key threat factors across the PAs, based on the PASI and PARTI values, this study has also enabled identifying [the three] PAs that are relatively most susceptible and threatened to the threat factors. Accordingly, threat factors such as canal construction for the purpose of sugar cane plantation, and investment developments that ultimately change the landscape and (conversion of grassland/bushland) in the ONP, are key issues that should be addressed in a matter of urgency, as well as expansion of human settlements and elephant poaching in the BES. Similarly, gold mining and irrigation farming along the course of the Tacazze River in the KSNP are top priority issues to be dealt with in the short term. Livestock grazing is a common practice across the protected areas, except in CCNP; and thus, requires implementation of regulatory systems across all protected areas, if prevention may not be possible at all, so as to ensure sustainability of ecosystems. Further, although incidences of human-wildlife conflicts are also identified to be among threats to other PAs in Ethiopia, including BES and KSNP (Kiringe and Okello, 2007; Wale et al., 2017; EWCA, 2018), it is a major threat factor in the CCNP (Acha and Temesgen, 2015; Megaze, 2017). This growing human-wildlife conflict in CCNP is a function of human population increase and encroachment into the park, and arises from conflicts between human and wildlife needs; particularly these are due to livestock depredation, crop-raiding by ungulates and human damage by elephants and buffalos (Acha and Temesgen, 2015; Megaze, 2017). Any action such as controlling problem animals would reduce negative attitudes to protected areas (Kiringe and Okello, 2007; Asefa and Didita, 2018).

Overall, the few facts discussed above illustrate the importance of the approach used to assess and rank the threat factors, as well PAs, in that the findings can be used to identify specific problems ailing each conservation area in a prioritized manner and deal with them on an individual basis, based on their severity indices or relative threat factor severity index (RTFSI). It is critical for EWCA to have structured and focused priorities for its PAs. This study, therefore, suggests that most of management actions should be based on actual measurement of threat indices or a reliable index such as RTFSI in addressing specific threat factors. Despite the similar trend reported herein between PA relative threatened index (PARTI) and susceptibility index (PASI), this study recommends that further prioritization of PAs most affected should be done based on a threat status using indices such as PARTI, rather than on susceptibility (PASI), which is simply a catalogue of threats recorded without considering its magnitude or severity (Kiringe and Okello, 2007).

### **Impacts of the threat factors to biodiversity in the protected areas**

Similar to some previous studies conducted in some of the PAs (e.g., EWCA, 2018; Gebre, 2018; Hika et al., 2018), the results of the present study demonstrated that most of the threat factors identified are posing adverse impacts on ecosystems, communities and species in the PAs. For instance, of the total 547 incidences of wildlife mortalities reported from ONP, 371 (68%) of the cases were due to subsistence and commercial poaching (Gebre, 2018). Similar reports (e.g., EWCA, 2015) have also indicated increasing trend of wildlife poaching, with elephant poaching for ivory, in particular, remaining the most severe immediate threat facing all populations of the species in the country. For example, 20 elephants were killed in the MNP only from 2012-2014 (Hika et al., 2018); 6 elephants between 2017/2018 in the BES (EWCA 2015; BES, 2018); and 8 elephants were killed in the KSNP between 2006-2015 (Shoshani et al., 2004; EWCA, 2018). In general, elephant poaching in Ethiopia has led to a decline in its populations by 90% since the 1980s and extirpation from at least 6 of the 16 areas in which elephants were found in the early 1990s (EWCA, 2015). In addition to elephant, however, the interviewees have also informed that indiscriminate poaching, interactively with other threat factors though, have ultimately resulted in the extinction of several mammal species from the five PAs, including Giraffe, Rhino, Oryx, Tiang, Zebra, Gerenuk and Grant's Gazelle in the Mago NP; and Zebra, Oryx and Rhino in the ONP.

Concerning settlement and cultivation (both small-scale subsistence and large-scale permanent), expansion inside Ethiopia's protected areas 14 villages (12 outside and 2 inside) are situated in/around the KSNP, with their ~64,000 estimated people (EWCA, 2018). As a result, ~415 km<sup>2</sup> (18% of the total area of the park) of natural habitat have been converted to sesame and sorghum cultivation fields.

Pastoralism and incursion into the PAs have caused disturbance and habitat degradation and loss within the parks. As a result, the elephant range of MNP has decreased by more than 52% since the 1980s (Demeke, 2008), with similar devastation occurring in the key habitats of the Babille elephant population. Over grazing by the livestock is a serious problem in KSNP mainly during the rainy season when the lands outside the park are covered by crops. During this season, on average ~520,000 to 530,000 heads of livestock from the surrounding areas and other parts of Tigray region, and from Eritrea as well, use the park for grazing year-round (EWCA, 2018).

Although a localized threat factor, only occurring in the KSNP and ONP, agricultural investment/irrigation canals are among the top ranked threat factors in these areas. In KSNP, nearly 15 km<sup>2</sup> of natural vegetation of the park have been cleared and converted by local private investors to irrigation-based banana plantation along the

Tekeze River (Wendim et al., 2014). In the case of ONP, establishment of the Omo-Kuraz Sugar Factory Project in the lower Omo Valley may perhaps represent one of the most environmental devastations that occurred in the country due to government led investment expansion. Similarly, a state-owned Sugar Factory Project, currently established in the core wildlife habitats in the ONP, is now affecting the park because of construction of roads, bridges, irrigation canals, sugar factories, accommodations for migrant workers, and land clearing for sugarcane plantation (Gebre, 2018). This happened as the process was non-inclusive of relevant stakeholders, like EWCA, during feasibility studies of the project. Thus, the environmental impacts that the development might have (as is now clearly evident) were not assessed and mitigation measures are not in place. As a result, over 25,000 ha of virgin land (grassland and bushland) of the park has been converted to sugar cane fields (Gebre, 2018).

Human-wildlife conflict (HWC), particularly with elephants, is a serious problem occurring in the KSNP and CCNP and BES, which mainly is caused by overlap in spatial distribution of human socio-economic activities and elephants' distribution range. In KSNP, the conflict is occurring on the irrigated land in the park, with elephants being chased and in other cases there is some equipment destruction by elephants; while in Chebera the damages are due to elephants' attraction to crops outside the boundary (bananas, sugar cane, cassava, etc.). Even though this human elephant conflict (HEC) in KSNP and CCNP occurs at a low rate, it is a critical challenge in BES. Conflict and crop raiding mainly results from the illegal settlement within the BES as 50 to 90% of incidents are within the park along both sides of the Gobebe Valley and the upper part of the Erer Valley. Reports indicate that, as a result of HEC, 19 human deaths and/or injuries had occurred between 1997 and 2014 (EWCA, 2015); and 3 human deaths/injuries occurred only in 2018 (BES, 2018). Although this may not be seen as a direct threat to elephants, but not that it is a significant problem to BES staff, and has led to decreased support for elephant conservation and a scale up of poaching as a result.

Another localized threat factor whose impacts should not be ignored is traditional gold mining by local people in the KSNP. Wendim et al. (2014) have reported from the KSNP ~10,000 gold mining pits (that is, 56 pits per km), that have 20-35 m depths, are established at ~300 traditional gold mining quarrying sites. Apart from modifying the ecosystem through ecological successions, such activities pose a significant threat to wildlife, because such pits can act as a trap even for larger animals like elephants (Wendim et al., 2014).

## CONCLUSION AND RECOMMENDATIONS

This study has found that wildlife poaching, cultivation expansion for subsistence farming and livestock

overgrazing are identified to be the top severe and widespread threat factors, occurring almost in all PAs. The underlying causes of the threat factors, in addition to a number of political/policy issues, include: Poor law enforcement (due to resource constraints and lack or poor implementation of enabling policies), availability of fire arms, ethnic conflicts, and increased global demand for, and price of, ivory. The results also demonstrated that the threat factors have posed irreversible adverse impacts on some ecosystem components, including key wildlife species such as elephant and their habitat. The Theory of Change Model (Figure 3) constructed would help EWCA and respective PA managers to implement the suggested interventions in the model.

From a methodological point of view, this study has demonstrated that the use of expert's opinion for rapid PA threat assessment to be valuable approach, particularly where resource constraints prevent detail ecological field surveys such as the case of a country like Ethiopia. In line with arguments of Raymond et al. (2010) and Pyhälä et al. (2019), the rationale to use this approach is that PA managers/experts are capable to identify and rank threats, identify target biodiversity component affected, identify obstacles to improving it and possible solutions to abate the threats and their impacts.

In summary, in order to improve the population status of elephants and the quality of their habitat (both of which are presumed to be affected by the threat factors), the top severe threat factors (that is, poaching, cultivation, settlement, investment, fire, etc.) should be prioritized in all PAs. Therefore, the suggested key management interventions shown in the theory of change models should be implemented as a matter of urgency and the effects (results = outputs, outcomes and goals) of these interventions on the proposed goals should be monitored based on the periodic evaluation/monitoring of the status of the target biological components (e.g., elephant population and habitat quality).

## CONFLICT OF INTERESTS

The authors have no any conflict of interests to declare.

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## ABBREVIATIONS

**EWCA**, Ethiopian Wildlife Conservation Authority; **FDRE**,

Federal Democratic Republic of Ethiopia; **PA(s)**, protected area(s); **RTFSI**, Relative Threat Factor Severity Index; **PARTI**, Protected Area Relative Threatened Index; **CCNP**, Chebera Churchura National Park; **KSNP**, Kafta Sheraro National Park; **MNP**, Mago National Park; **ONP**, Omo National Park; **BES**, Babile Elephant Sanctuary.

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*Full Length Research Paper*

# Typology of coffee-based agroforestry systems in the semi-deciduous forest zone of Togo (West Africa)

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**This study contributes to the knowledge of the variants of coffee-based agroforestry systems (CAFS) of the semi-deciduous forest zone of Togo. To achieve this, forest, floristic and ecological data were collected in 163 random plots of 25 m × 25 m (625 m<sup>2</sup>), to analyze the typology of the CAFS and their characteristics across the study area. In the 10.1875 ha surveyed, results showed a total of 2510 stems of woody plants belonging to 138 species and 38 families. The average tree density was 246.38 trees/ha, whereas the basal area was 27.99 m<sup>2</sup>/ha. Four types of CAFS have been identified; the first type (G1) is the plant communities dominated by *Milicia excelsa* and *Persa americana* associated with coffee trees; the second type (G2) is characterized by CAFS with *Albizia* spp. and *Citrus sinensis* as dominant woody species; the third group (G3) is composed of communities dominated by *Albizia adianthifolia* and *Milicia excelsa* and the fourth group (G4) consists of CAFS dominated by *M. excelsa* and *Antiaris africana*. The floristic composition showed that the latter CAFS (G4) dominated by *M. excelsa* and *A. africana* was the most diversified, more rich in term of species (Species richness = 110, Shannon index = 4.06) and of which the basal area (Basal area = 34.32 m<sup>2</sup>/ha) is larger than the others.**

**Key words:** Coffee-based agroforest system, typology, semi-deciduous forest zone, Togo.

## INTRODUCTION

In the world, forests play an important role in maintaining fundamental ecological processes, such as water regulation, carbon storage, the provision of livelihoods and support economic growth (de Groot et al., 2002; Holvoet and Muys, 2004; Gurung and Seeland, 2008; Thompson et al., 2011; Abson et al., 2014; Sears et al., 2018). However, nowadays, these forests are facing

serious degradation resulting from important over-exploitation, intensive agriculture, especially in developing countries (Lawson et al., 2014; Duguma et al., 2019). This situation is due to the fact that people are looking for more fertile lands to increase their food production and ensure their food security and economic well-being. Forest degradation started with the increase in human

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population and increasing food demand (Bargali et al., 2009). To overcome this situation, farmers began the agroforestry practices after clear-cutting the natural forests (Bradstock, 1981; Bargali and Singh, 1991; Bargali et al., 1992a, b) which have adversely affected the nutrient cycling and decomposition processes in the soil system (Bargali et al., 1993; Bargali, 1995; 1996). This happens most of the time through shifting agriculture (or slash and burn agriculture) consisting of the clearing of forest lands in order to grow crops until the soil is exhausted of nutrients and/or the site is overtaken by weeds. Once the soil is exhausted, they move elsewhere to clear more forests (Chakravarty et al., 2012). It is important to conciliate food production systems and the maintenance of ecosystem services of the vegetation. In this sense, agroforestry is reported to be an interesting and effective option to decrease the loss of forests, to conserve the biodiversity and to provide important sources of income for the local population (Current et al., 1995; Schroth et al., 2004a; Ashley et al., 2006; Steffan-Dewenter et al., 2007; Mbow et al., 2014a, b, c; Reed et al., 2017).

Agroforests are the most forest-like in their structure and appearance of all agroforestry systems. Some of them may be easily mistaken for the natural forests (de Foresta et al., 2000; Schroth et al., 2004b). Agroforestry systems occur in all tropical regions and can be based on many different tree crop species, among which are the coffee-based agroforestry systems (hereafter CAFS). According to Donald (2004), the wet lowland intertropical regions of Africa, America, and Asia are favorable to *Coffea robusta* agroforestry systems, whereas *Coffea arabica* agroforestry systems are found in highland regions of Africa and Latin America. CAFS conserve a large number of forest species (Correia et al., 2010) since coffee is grown in forest areas with high plant species diversity (Somarriba et al., 2004; Toledo and Moguel, 2012). Several studies have been carried out in coffee-based agroforestry systems in Latin America (Peeters et al., 2003; Lopez-Gomez et al., 2008; Valencia et al., 2015; González-Zamora et al., 2016), in Eastern Africa (Kenya: Pinard et al., 2014, Ethiopia: Aerts et al., 2011; Uganda: Negawo and Beyene, 2017). In West Africa, studies on CAFS are scarce (Correia et al., 2010), and most of the works are focused on cocoa-based agroforestry systems (Ghana: Kyereh, 2017; Abdulai et al., 2018; Côte-d'Ivoire: Dumont et al., 2014; Kpangui et al., 2015).

In Togo, coffee is grown in the subhumid zone that is characterized by the presence of semi-deciduous forests. Indeed, the first test to introduce *C. arabica*, in the semi-deciduous forests by the German colonizer, was from 1895. New efforts, by the French administration from 1925 were a failure. Farmers will be interested in coffee, only after the establishment of cocoa farms, during the 1940s. It will then be *C. robusta*, less fragile than *C. arabica*. Currently, only *C. robusta* vulgarized by SRCC

(Coffee and Cocoa Cropping Renovation Society) in the 1970s, is the most widespread and cultivated, *C. arabica* has disappeared. In this zone, many studies were conducted on forests (Akpagana, 1989; Guelly, 1994; Adjossou, 2004, 2009), but were not really focused on the CAFS. Guelly (2000) focused on the importance of *Albizia* spp. in some CAFS in forest reconstitution while Koda (2013) also showed the conservation of biodiversity in CAFS, but these works did not cover the whole area and therefore did not allow to have an overall knowledge on the actual floristic composition of these CAFS. Despite their ecological and socio-economic importance, the diversity and composition of these systems are not well known.

In this regard, the objective of this study was to contribute to the knowledge of the composition of the CAFS in the forest zone of Togo. Specifically, this work intended to assess the diversity of coffee farms, to establish the typology of CAFS and to characterize them.

## MATERIAL AND METHODS

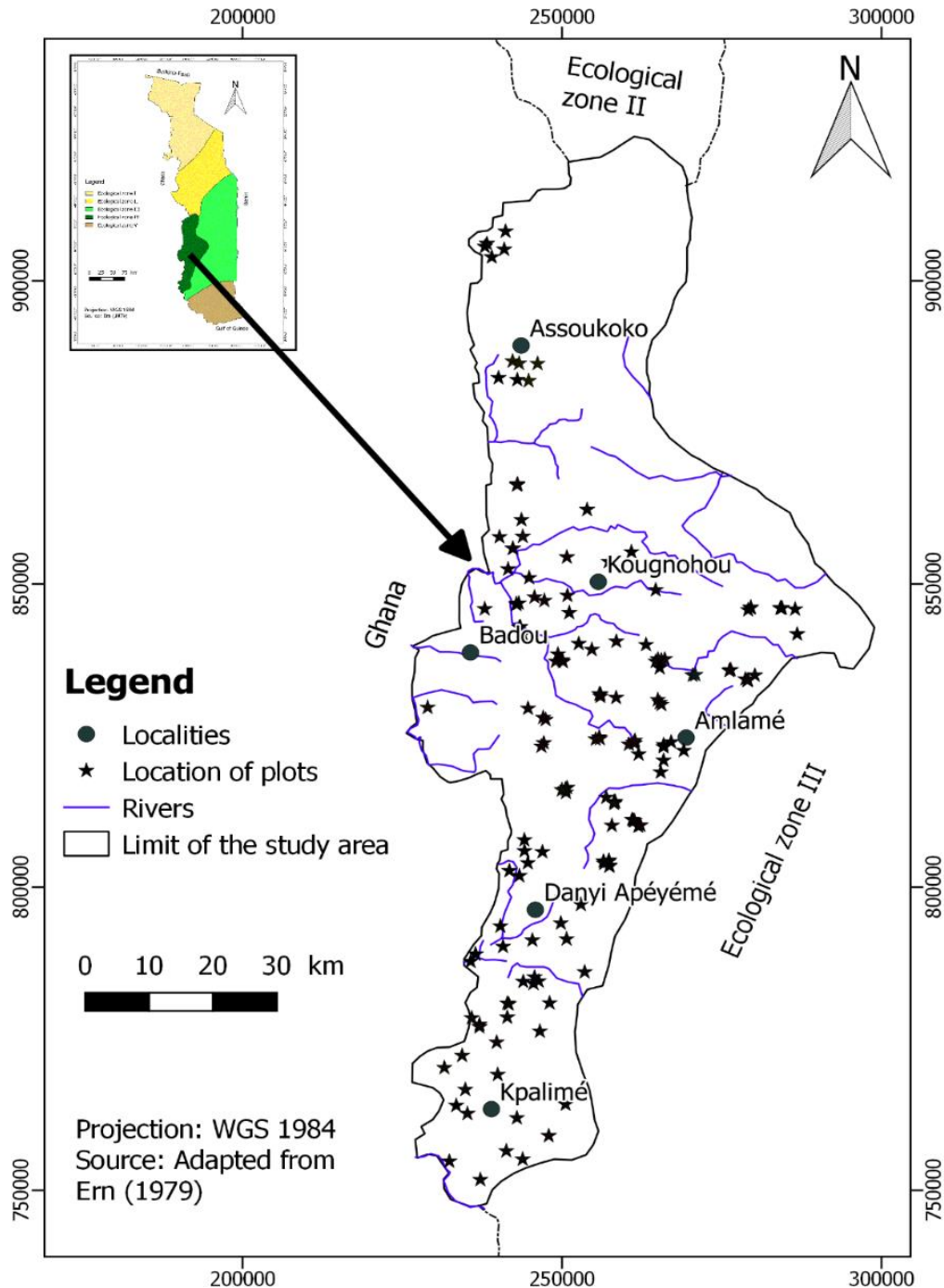
### Study area

The study area represents the unique zone of Togo with semi-deciduous forests and favorable for coffee cultivation, as well as cocoa. It is one of the 5 ecological zones (ecological zone IV) of Togo (Ern, 1979). It extends between 6°15 and 8°20 latitude North and 0°30 and 1°20 longitude East (Figure 1). This zone is the meridional portion of the Atakora mountain chain. The total land mass of the study area is about 65,000 ha. Geologically, the main structural unit of the study area is the Atakorian, composed of epimetamorphic formation (Bessoles and Trompette, 1980). This zone is also composed of amphibolite epidote, amphibolitic gneiss, pyroxene gneiss and amphibole-pyroxenite (Kounétsron and Seddoh, 1978). The pedology is dominated by slightly evolved soils, ferrallitic soils, and leached ferruginous tropical soils. The zone benefits from transitional subequatorial climate (Papadakis, 1966; Trochain, 1980) characterized by annual rainfall and temperatures varying between 1390 mm and 1700 mm, and 22.5°C and 26°C, respectively. Regarding the vegetation, Togo is located in the Dahomey corridor being the interruption of the West-African forest block by the savanna that covers up to the coastal zone. The study area appears as the continuation of the humid and semi-deciduous forests of Ghana (Hall and Swaine, 1981). According to Akpagana (1989), the vegetation of the sub-humid mountainous zone of Togo is constituted of the humid semi-deciduous forest. However, it has become the zone of forest remnants with the most important plant diversity found in remote areas with difficult access (Adjossou, 2009).

### Data collection

To determine the typology of CAFS and their structural characteristics, forestry inventories were conducted in the coffee farms (coffee based farming systems) of the study area. Clearly, 163 sampling plots of 25 m × 25 m (625 m<sup>2</sup>) were established randomly in representative sites over the study area, taking into consideration the CAFS (Figure 1). The total surface area inventoried in this study, was 10.1875 ha for associated species.

The geographical locations of the sampling plots were recorded using a handheld GPS Garmin 64S. In each plot, all woody species,



**Figure 1.** Location of sampling plots over the study area.

occurring in the CAFS, were recorded. The diameters at breast height (dbh) (1.3 m from the ground) of trees greater than, or equal to, 5 cm in diameter were recorded using a diameter measuring tape. The total height of these species, expressed as meters, was estimated with a "Suunto" clinometer. An abundance-dominance coefficient has been assigned to each species. Most of the species have been directly identified on the field. The unidentified species in the field were sampled and taken to the Laboratory of Botany and Plant Ecology (University of Lomé, Togo) for identification purposes.

The species identification was based on the use of supporting documents of Brunel et al. (1984) and Akoegninou et al. (2006) as well as the Herbarium of the University of Lomé.

Regarding coffee plants measurement, sub-plots of 10 m × 10 m (100 m<sup>2</sup>) were installed within plots of 625 m<sup>2</sup>. These measurements were made on the diameter (at 50 cm) aboveground, for plants that were greater than, or equal to, 3 cm in diameter; and additionally the total height of the coffee plants was assessed and expressed as meters. The total surface area surveyed was 1.6 ha.

**Table 1.** Formulas of different indices used in this study.

| Indices                | Equation                               |
|------------------------|--|
| Shannon index (H)      | $H = - \sum (Ni/N) \text{Log}_2(Ni/N)$ |
| Pielou's evenness (E)  | $E = H/\text{Log}_2N_0$                |
| Rarefaction index (RI) | $RI = [1-(Np/Ntp)]^*100$               |

Ni: Individuals number of a given species; N: Total individuals number;  $N_0$ : Total number of species recorded; Np: Number of plots where a given species is found; Ntp: Total number of plots.

**Table 2.** Formulas used to calculate the structural parameters and the IVI.

| Indices                           | Equation   |
|-----------------------------------|--|
| Density of trees (D) in trees/ha  | $D = Nt/S$   |
| Basal area (gi) in $m^2/ha$       | $gi = (\pi \times d^2)/4$                            |
| Importance value index (IVI) in % | $IVI = \text{FREQsp} + \text{DENSsp} + \text{DOMsp}$ |
| Relative frequency (FREQsp) in %  | $\text{FREQsp} = (Np/Ntp) \times 100$                |
| Relative density (DENSsp) in %    | $\text{DENSsp} = (Ni/Nt) \times 100$                 |
| Relative dominance (DOMsp) in %   | $\text{DOMsp} = (gi/\Sigma gi) \times 100$           |

Nt: Total number of trees; S: area in hectare; d: Diameter of trees; Np: Number of plots where the species is found; Ntp: Total number of plots; Ni: number of trees of a given species; gi: Basal area.

## Data analysis

### Estimation of plant species richness, diversity, and frequency

The nomenclature used for species and families was the flora of Brunel et al. (1984) and Akoégninou et al. (2006), following the Angiosperm Phylogeny Group (APG) III (2009). Plant species richness of associated species was obtained by establishing the list of species occurring in the CAFS. The diversity was evaluated by computing the Shannon and Pielou's evenness (Magurran, 2004) indices and the frequency of species was determined using the rarefaction index (Rarity-weighted Richness Index), according to the equation of Géhu and Géhu (1980) (Table 1). The following thresholds have been set: rare species with  $RI > 80\%$  and frequent species with  $RI < 80\%$  (Adomou, 2005).

### Life forms and chronological affinities

The life forms of associated species were determined according to Raunkiaer (1934), revised by several studies in tropical regions (Aké-Assi, 1984; Lebrun, 1981; Aké-Assi, 2001). They are phanerophytes and Geophytes. Chorological affinities were defined based on the chorological distribution of Africa Aké-Assi (1984), adapted to the classification of Evrard (1968) and White (1986).

### Structural parameters

Using the formulas as in Table 2, basal area (gi) and densities (D) were calculated for associated plant species recorded in the CAFS. The importance value index (IVI) as described by Curtis and McIntosh (1950) was computed for each species. The distribution of CAFS trees by diameter and height classes-size has been done.

### Analysis of the typology of plant communities in CAFS

Plots were submitted to a Hierarchical Clustering Analysis with R

software, following the Euclidian distance and the Ward method using "Vegan" package. Groups from coffee-based agroforestry systems were discriminated according to Hierarchical Clustering Analysis and named taking into account the importance value index.

## RESULTS

### Richness, floristic diversity and species frequency of CAFS

In total, 2510 stems were recorded in coffee-based agroforestry systems. These stems belonged to 138 species, 110 genera, and 38 families. The most represented families were *Moraceae* (15 species), *Mimosaceae* (14 species), *Euphorbiaceae* (10 species), *Caesalpinaceae* (7 species), *Meliaceae* (7 species) and *Sterculiaceae* (7 species). *M. excelsa*, *Albizia* spp. (*A. adianthifolia*, *A. zygia*), *A. africana*, *Persea americana*, *Citrus sinensis*, *Khaya grandifoliola*, *Aubrevillea kerstingii*, *Cola nitida* were the most frequent species in the investigated CAFS (Table 3). The rarefaction index (RI) revealed that all the species associated to CAFS were frequent (RI value  $< 80\%$ ), even though some species (*K. grandifoliola*, *A. kerstingii*, and *C. nitida*) had RI values close to the threshold.

In general, the analysis of the ecological characteristics showed that, the basal area and trees density of associated species were respectively, 27.99  $m^2/ha$  and 246.38 trees/ha. Details of these ecological parameters are provided for the different types of CAFS identified in this study. Concerning coffee plants, all the calculated

**Table 3.** Frequent species in coffee-based agroforestry systems.

| Species   | Family        | Chorological affinities | Life forms | Rarefaction index (%) |
|---|---------------|-------------------------|------------|-----------------------|
| <i>Milicia excelsa</i> (Welw.) C. C. Berg.                                  | Moraceae      | GC                      | MP         | 35.58                 |
| <i>Albizia adianthifolia</i> (Schumach.) W. Wight var. <i>adianthifolia</i> | Mimosaceae    | GC                      | mP         | 48.47                 |
| <i>Albizia zygia</i> (DC.) J.F. Macbr                                       | Mimosaceae    | GC                      | mP         | 50.31                 |
| <i>Antiaris africana</i> var. <i>africana</i> (Engl.) C.C.Berg              | Moraceae      | GC-SZ                   | mP         | 58.90                 |
| <i>Persea americana</i> Mill.   | Lauraceae     | I                       | mp         | 69.94                 |
| <i>Citrus sinensis</i> (L.) Osbeck  | Rutaceae      | I                       | mp         | 76.07                 |
| <i>Khaya grandifoliola</i> C. DC.   | Meliaceae     | GC                      | mP         | 78.53                 |
| <i>Aubrevillea kerstingii</i> (Harms)                                       | Mimosaceae    | GC                      | MP         | 79.14                 |
| <i>Cola nitida</i> (Vent.) Scott. and Endl.                                 | Sterculiaceae | GC                      | mP         | 79.75                 |

Note: GC-SZ: Guineo-congolian\_soudano-Zambezian; MP: Megaphanerophytes; mP: Mesophanerophytes; mp: Microphanerophytes; GC: Guineo-congolian; I: Introduced species.

**Table 4.** Calculated parameters for coffee trees.

| Parameter                       | Value       |
|---------------------------------|-------------|
| Density (coffee plants/ha)      | 2670        |
| Basal area (m <sup>2</sup> /ha) | 7.85        |
| Mean diameter (cm)              | 5.58 ± 2.5  |
| Mean height (m)                 | 3.89 ± 1.11 |
| Total surface Area (ha)         | 1.6         |

parameters are summarized in Table 4.

### Typology and characteristics of coffee-based agroforestry systems

Based on the hierarchical Clustering Analysis and at the threshold of 78.5%, 4 different groups of plots were identified according to their floristic composition, the abundance/dominance Importance Value Index (IVI) and observations made on the field (Figure 2).

#### Coffee-based agroforestry systems with *M. excelsa* and *P. americana* (G1)

This group is constituted of 44 plots. It was the CAFS with *M. excelsa* (IVI = 110.73%) and *P. americana* (IVI = 73.83%) as important species. The species richness was 79 species. The density of associated species was 198.18 trees/ha and the basal area had a value of 23.81 m<sup>2</sup>/ha. Shannon's index and Pielou's evenness index were 3.82 and 0.87, respectively. In this group, the Guineo-Congolian species were most represented with 54.67% of all individuals whereas Mesophanerophytes and Microphanerophytes were 41.83% and 29.35%, respectively (Figure 3).

#### Coffee-based agroforestry systems with *Albizia* spp (*A. zygia* and *A. adianthifolia*) and *C. sinensis* (G2)

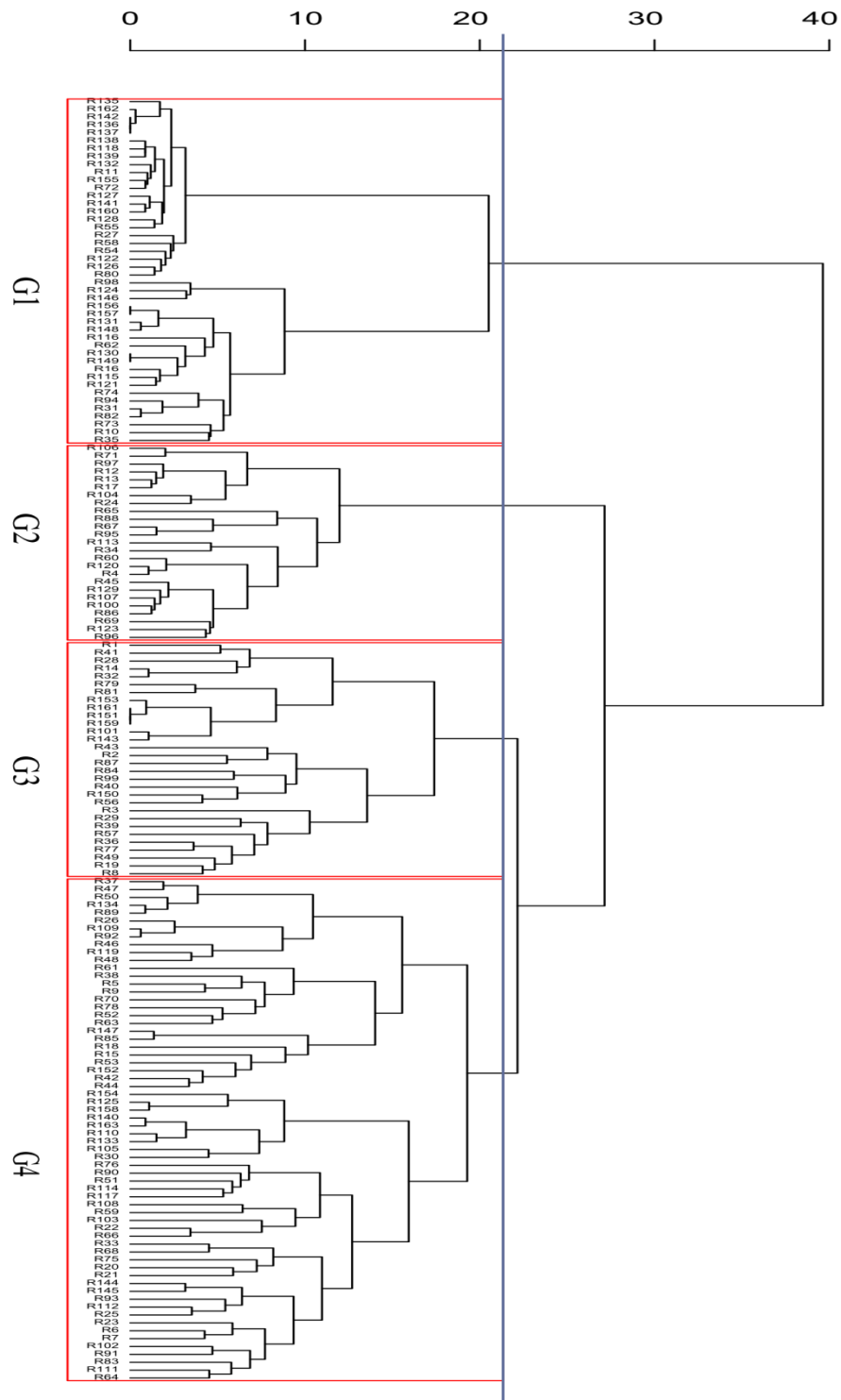
Twenty-five (25) plots belonged to this CAFS. It represented coffee farms in association with *Albizia* spp (*A. zygia* and *A. adianthifolia*) with an IVI value of 223.01%, and *C. sinensis* (IVI=61.97%). The species richness, tree density, and the basal area were 62 species, 254.08 trees/ha 29.52 m<sup>2</sup>/ha, in the respective order. Shannon index was 3.58 and Pielou's evenness 0.86. Regarding the phytogeographical affinities, the Guineo-Congolian species were the most important with 56.67% of all individuals. The Mesophanerophytes were represented by 56.42% of individuals (Figure 3).

#### Coffee-based agroforestry systems with *A. adianthifolia* and *M. excelsa* (G3)

This group is composed of 30 plots. It is the CAFS with *A. adianthifolia* (IVI=122.27%) and *M. excelsa* (IVI=76.97%). The species richness was 73 species. The tree density had been 253.33 ind/ha whereas the basal area was evaluated to 28.18 m<sup>2</sup>/ha. The Shannon index and Pielou's evenness were respectively estimated to 3.73 and 0.86. Guineo-Congolian species were the most represented (68.63%) while the Mesophanerophytes (61.26%) were the predominant life form (Figure 3).

#### Coffee-based agroforestry systems with *M. excelsa* and *A. africana* (G4)

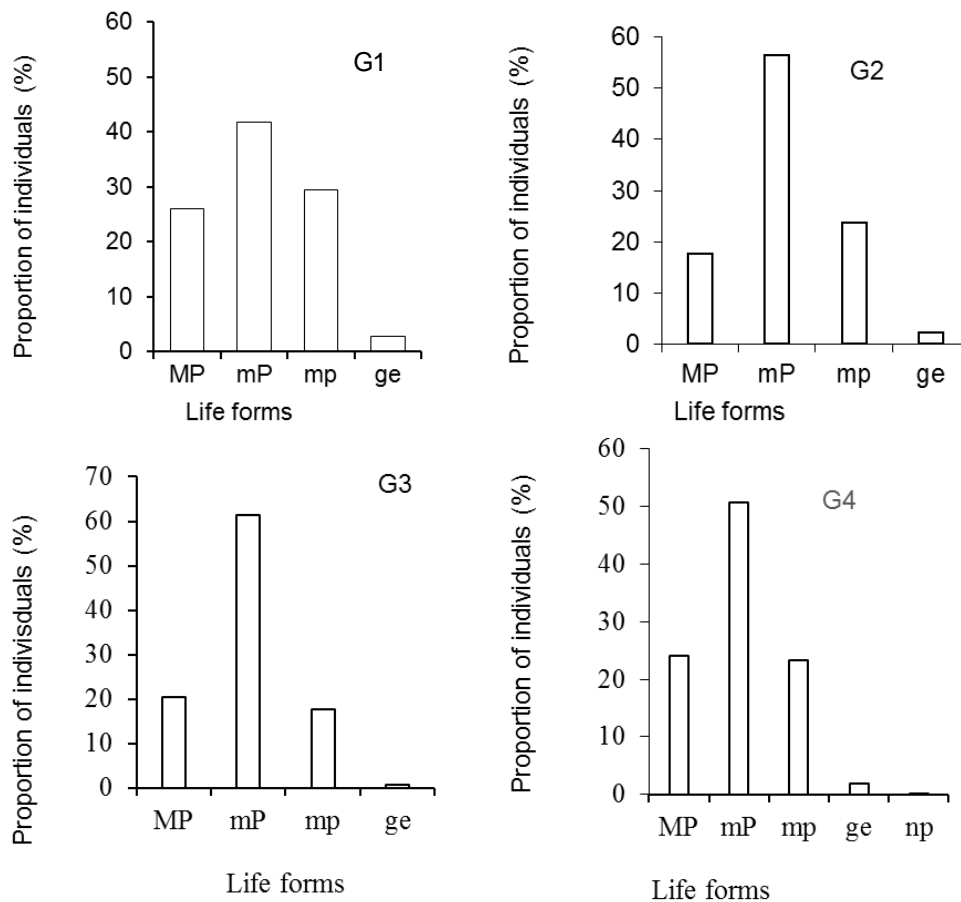
This cluster included the most important number of plots(64). It was the group of CAFS with *M. excelsa* (IVI = 104.47%) and *A. africana* (IVI = 82.69%) as important associated species. The Shannon index and Pielou's evenness were 4.06 and 0.86. The density was 273.25 ind/ha for species richness of 110 species and a basal



**Figure 2.** Hierarchical Clustering showing the discrimination of different variants of CAFS

area of 30.17 m<sup>2</sup>/ha. The Guineo-Congolian (GC and GC-SZ) were the most represented with 59.83% and 24.06% of the individuals. Mesophanerophytes were more important (50.77%), followed by Megaphanerophytes

(23.97%) and Microphynerophytes (23.23%) (Figure 3). All the calculated values of the Importance Value Indices and the values of floristic and structural characteristics of identified types of CAFS are summarized respectively, in



**Figure 3.** Spectrum of life forms. MP: Megaphanerophytes; mP: Mesophanerophytes; mp: Microphanerophytes; np: Nanophanerophytes; ge: Geophytes

Table 5 and Table 6.

## Structures of coffee-based agroforestry systems

### Diameter class distribution

The distribution of CAFS trees by diameter class-size showed a distribution whose appearance was similar to an "L"-shaped curve or inverted "J" type (Figure 4). This distribution characterized a structure with a predominance of individuals with small diameters (5 to 40 cm). The most represented diameters were comprised between 10 and 40 cm for all the CAFS types (*M. excelsa* and *P. americana*, *Albizia* spp. and *C. sinensis*, *A. adianthifolia* and *M. excelsa* and *A. africana*). Diameters from 50 to 100 cm are moderately represented in almost all groups. Trees with big diameters are scarce, except some among them that exceeded 200 cm observed in G4. The mean diameters of CAFS trees G1, G2, G3, and G4 are respectively  $31.7 \pm 19.36$  cm,  $31.26 \pm 21.06$  cm,  $32.23 \pm 19.38$  cm and  $33.96 \pm 21.93$  cm.

### Height class distribution

CAFS trees present a bell-shaped structure (Figure 5). This structure reflected the dominance of trees with medium height. The height class from 8 to 10 m is the most represented in all CAFS types. Heights greater than 20 m are less represented except in the CAFS dominated by *M. excelsa* and *A. africana* (G4) where individuals are more present. It is in this group that individuals with heights up to 30 m are found. The mean height is  $10.05 \pm 4.92$  m for the CAFS G1,  $10.52 \pm 4.44$  m for G2,  $10.96 \pm 4.12$  m and  $11.65 \pm 5.47$  m for G3 and G4, respectively.

## DISCUSSION

### Floristic composition and species frequency

The study of agroforestry coffee systems enabled to have an idea about their floristic composition and the available species. The floristic structure analysis showed that *Moraceae* is the most represented family and species in

**Table 5.** Importance Value Indices of the different types of CAFS.

| Group | Species  | FREQsp<br>% | DENSsp<br>% | DOMsp<br>% | IVI %  |
|-------|--|-------------|-------------|------------|--------|
| G1    | <i>M. excelsa</i> (Welw.) C. C. Berg.                                  | 72.73       | 18.17       | 19.84      | 110.74 |
|       | <i>P. americana</i> Mill.  | 52.27       | 14.31       | 7.25       | 73.83  |
| G2    | <i>A. zygia</i> (DC.) J.F. Macbr.                                      | 92.00       | 19.40       | 21.18      | 132.58 |
|       | <i>A. adianthifolia</i> (Schumach.) W. Wight var. <i>adianthifolia</i> | 68.00       | 12.85       | 9.59       | 90.44  |
|       | <i>C. sinensis</i> (L.) Osbeck   | 48.00       | 10.08       | 3.89       | 61.97  |
| G3    | <i>A. adianthifolia</i> (Schumach.) W. Wight var. <i>adianthifolia</i> | 90.00       | 14.74       | 17.54      | 122.27 |
|       | <i>M. excelsa</i> (Welw.) C. C. Berg.                                  | 56.67       | 8.84        | 11.46      | 76.97  |
| G4    | <i>M. excelsa</i> (Welw.) C. C. Berg.                                  | 76.67       | 10.06       | 17.74      | 104.47 |
|       | <i>A. africana</i> var. <i>africana</i> (Engl.) C.C. Berg              | 61.67       | 8.69        | 12.33      | 82.69  |

FREQsp: Relative frequency; DENSsp: Relative density; DOMsp: Relative dominance; IVI: Importance value index.

**Table 6.** Values of floristic and structural characteristics of identified types of CAFS.

| Floristic characteristics                     | G1     | G2     | G3     | G4     |
|---|--------|--------|--------|--------|
| Shannon index                                 | 3.82   | 3.58   | 3.73   | 4.06   |
| Pielou's evenness                             | 0.87   | 0.86   | 0.86   | 0.86   |
| Species richness                              | 79     | 62     | 73     | 110    |
| Density (trees/ha)                            | 198.18 | 254.08 | 253.33 | 273.25 |
| Basal area (m <sup>2</sup> /ha)               | 23.81  | 29.52  | 28.18  | 34.32  |
| Megaphanerophytes (%)                         | 26.05  | 17.63  | 20.42  | 23.97  |
| Mesophanerophytes (%)                         | 41.83  | 56.42  | 61.26  | 50.77  |
| Microphanerophytes (%)                        | 29.35  | 23.67  | 17.68  | 23.23  |
| Nanophanerophytes (%)                         | 0      | 0      | 0      | 0.091  |
| Geophytes (%)                                 | 2.75   | 2.26   | 0.63   | 1.92   |
| Guineo-congolian species (GC) (%)             | 54.67  | 56.67  | 68.63  | 59.83  |
| Introduced Species (I) (%)                    | 26.23  | 16.87  | 8.42   | 15.37  |
| Guineo-congolian_soudano-Zambeian (GC-SZ) (%) | 19.08  | 26.19  | 22.94  | 24.06  |
| Soudano-Zambeian (SZ) (%)                     | 0      | 0.25   | 0      | 0.36   |

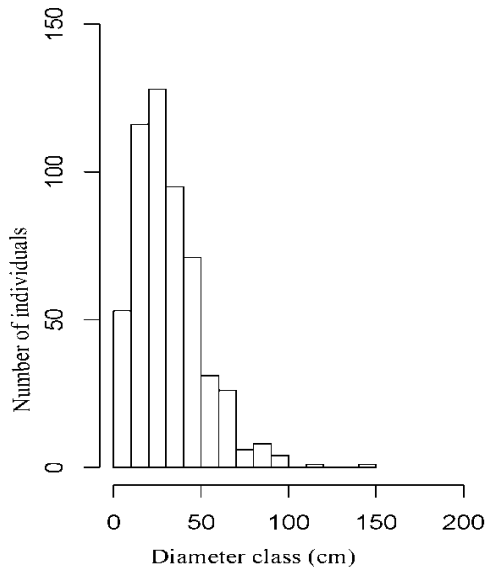
CAFS are in majority, semi-deciduous forest species (e.g., *M. excelsa*, *A. africana*, *Albizia* spp., etc.) and constitute the essential of secondary formations. These species were also the most represented and frequent in these agroforestry systems. Previous work of Akpagana (1989), Guelly (1994) and Adjossou (2009) have found similar results on the floristic composition of semi-deciduous forests in the study area (where CAFS are taking place). Likewise, the important representativeness of the *Moraceae* family has been highlighted by the work of Fouellefack Matsa Vougue (2015), in coffee-based agroforestry systems in Cameroon.

#### Tree density and phytogeographical affinities

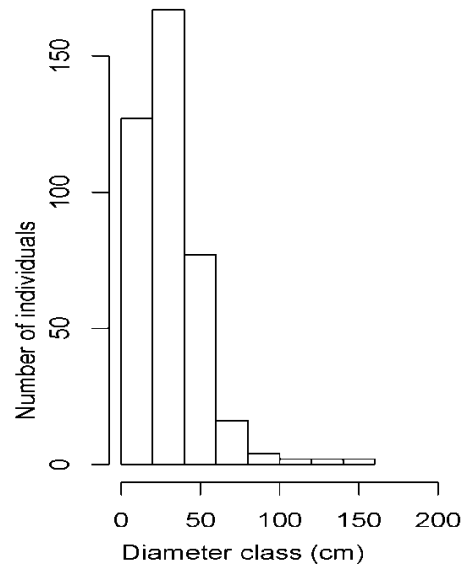
The result showed that the overall tree density in CAFS

was 246.38 ind/ha and varied between 198.1 in/ha and 273.25 ind/ha. Thus, these densities appear to be lower than results found by former works (Akpagana, 1989; Adjossou, 2004, 2009) in the forests of the same zone. In the meantime, the tree densities recorded in our study are higher than those reported (116 ind/ha) by Negawo and Beyene (2017) in Eastern Uganda, in a coffee-based agroforestry system. Nevertheless, our results are similar to values reported by other authors who have worked in coffee growing areas (Peeters et al., 2003; Lopez-Gomez et al., 2008; Correia et al., 2010). This situation can be explained by the fact that the coffee farms are more or less anthropized and are each time weeded, and therefore not as forest formations that are not always disturbed.

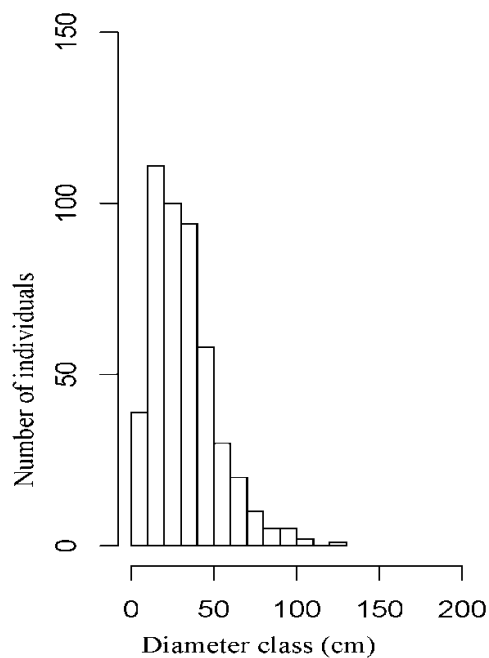
Coffee-based agroforestry systems are dominated by



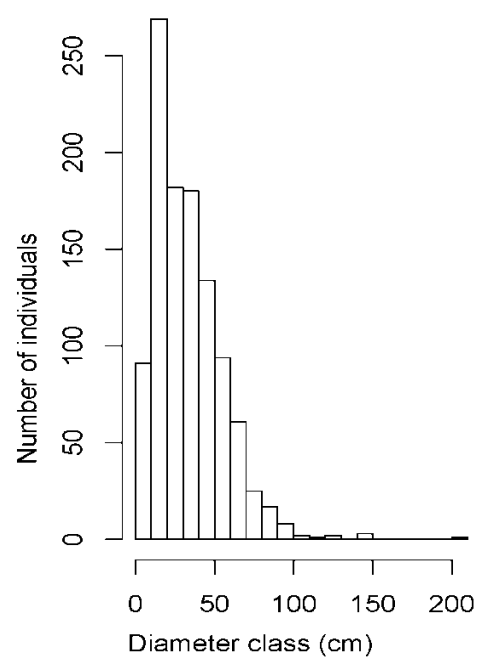
**G1: CAFS with *Milicia excelsa* and *Persea americana***



**G2: CAFS with *Albizia* spp. (*A. zygia* and *A. adianthifolia*) and *Citrus sinensis***



**G3: CAFS with *Albizia adianthifolia* and *Milicia excelsa***



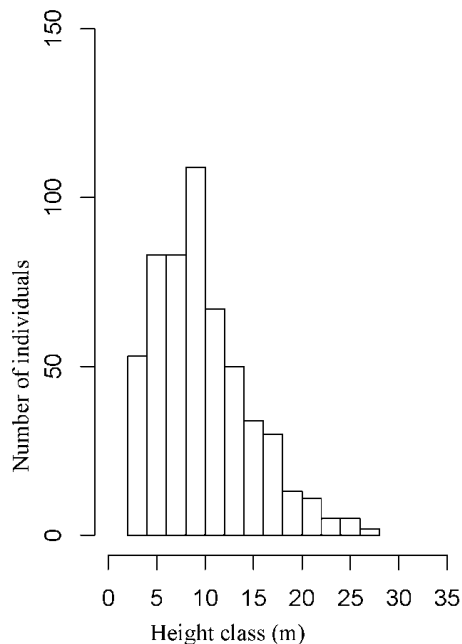
**G4: CAFS with *Milicia excelsa* and *Antiaris africana***

**Figure 4.** Diameter class distribution within the four types of CAFS

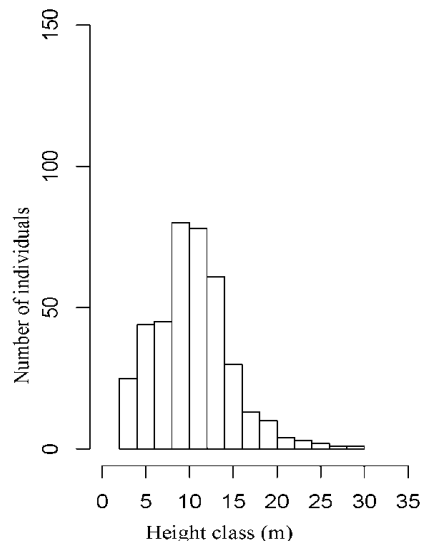
species such as *M. excelsa*, *Albizia* spp., *A. africana*, etc., typical of the forest climatic zone of Togo. Thus, the species recorded in our study area are in majority

Guineo-congolian. These results are similar to the works of Akpagana (1989); Guelly (1990); Guelly (1994); Adjossou (2009).

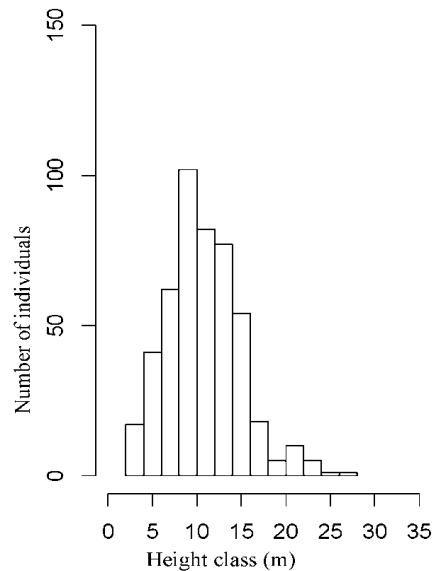




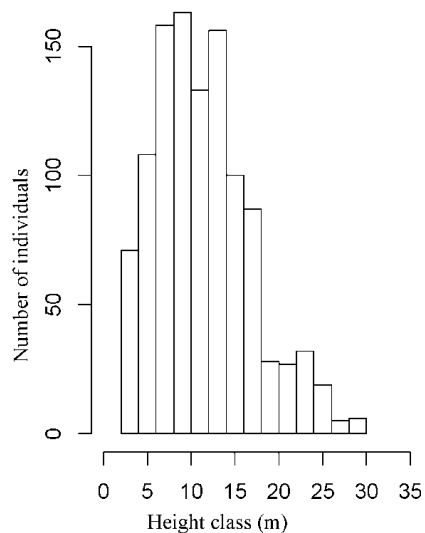
**G1: CAFS with *Milicia excelsa* and *Persea americana***



**G2: CAFS with *Albizia* spp. (*A. zygia* and *A. adianthifolia*) and *Citrus sinensis***



**G3: CAFS with *Albizia adianthifolia* and *Milicia excelsa***



**G4: CAFS with *Milicia excelsa* and *Antiaris africana***

**Figure 5.** Height class distribution within the four types of CAFS.

**Typology of coffee-based agroforestry systems**

Four types of coffee-based agroforestry systems were identified on the basis of importance values indices, species richness, and ecological descriptors. Indeed, *Albizia* spp. are plants of semi-deciduous forests and

constitute the essential of the secondary formations of the forest zone of Togo. They are heliophilous plants, having positive photosensitivity and are pioneer species that prepare the return back to the forest stage of these disturbed formations (Guelly, 2000). These CAFS with *Albizia* spp are the results of reforestation efforts

introduced by the SRCC (Coffee and Cocoa Cropping Renovation Society). Similarly, Depommier (1988a), pointed out that in CAFS in Burundi, shade plants were usually *Albizia* spp. in light foliage and *Senna spectabilis* in denser foliage. In addition to the shading role, *Albizia* spp. is reported to as a key component for maintaining the soil fertility (Depommier 1988b). This role of fertilization of *Albizia* spp. was also highlighted by other works (Kalanzi and Nansereko, 2014), in Uganda. Equally, our findings are also similar to those obtained by Nigussie et al. (2014), Hundera et al. (2015) and Endale (2019), who showed that *Albizia* spp. contribute to the improvement of soil fertility, in coffee-based agroforestry systems in Ethiopia.

The CAFS dominated by forest species such as *M. excelsa* and *A. africana* (G4) constitute the most old coffee-based systems. These species were preserved by the farmer during the clearing of undergrowth vegetation for the establishment of coffee farms. This association of *M. excelsa* and *A. africana* was identified by Adjossou (2009) in forests of the study area. Likewise, the abundance and dominance of *M. excelsa* and *A. africana* in CAFS have been reported by several authors in coffee cropping regions (Herzog, 1994; Correia et al., 2010). These species, combined with other native species in CAFS, give to these systems, an appearance similar to dense forests.

Furthermore, other observed groups, especially *P. americana* and *C. sinensis* in association with other species in coffee farms, have also been reported by authors who have worked in CAFS (Gwali et al., 2015; Gonzalez-Zamora et al., 2016). These fruit species are associated with coffee trees, especially because of their high economic value (Davis et al., 2017).

When considering the four categories of CAFS, it should be noted that the species richness, density, basal area and Shannon index are higher in type G4 (*M. excelsa* and *A. africana*) than the three others. This case can be explained by the fact that this type is made up of more forest species and therefore, more diverse and denser. This group also refers to the abandoned CAFS undergoing natural recovery towards denser vegetation, especially forests.

### Structure of CAFS

The distribution of CAFS trees by diameter class-size revealed an inverted “J” type. This distribution characterized a structure with a predominance of individuals with small diameters. This distribution seemed similar to that described in coffee-based agroforestry systems, in Ethiopia by (Mahmood, 2008) and in Guinea by Correia et al. (2010). This author pointed out that these patterns of diameter classes indicated the general trends of population dynamics and recruitment process. The abundance of young people individuals could be explained by germinations maintained by farmers. these

CAFS are dynamic with a balanced structure and a constant renewal of big trees. The scarcity of the big can be explained by the fact that the farmers use to cut sometimes the big trees.

### Conclusion

This study enabled to know the diversity and the different types of CAFS in the semi-deciduous zone of Togo, as well as the structural parameters that characterize them. In addition, this work revealed that CAFS can also conserve native trees. The investigations allowed to identify 138 ligneous species preserved by farmers for their different role on farms. Furthermore, coffee-based agroforestry systems have been allocated into four variants, according to the importance value indices of their species and ecological descriptors recorded during field work. These are CAFS with *Milicia excelsa* and *Persea americana*; CAFS in association with *Albizia* spp. and *C. sinensis*; CAFS with *A. adianthifolia* and *M. excelsa*; and CAFS in association with *M. excelsa* and *A. africana*. Among all these categories of CAFS, it should be indicated that the ones with *M. excelsa* and *A. africana* are the most species-rich and are therefore close to dense secondary humid forests.

### CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

### ACKNOWLEDGMENTS

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